7. *The* Atomic Weight *of an element is the number of times its atom is as heavy as an atom of hydrogen.* The atomic weights of oxygen, hydrogen, nitrogen, chlorine, carbon, sulphur, sodium, potassium, and calcium should be memorized, though in most examinations the required atomic weights are given.

O = 16 (this is the conventional method of expressing the sentence, 'The atomic weight of oxygen is 16'); H = 1; N = 14; Cl = 35·5; C = 12; S = 32; Na = 23; K = 39; Ca = 40.

8. The atomic weight of a solid element multiplied by its specific heat is approximately 6·4 (Dulong and Petit's *Law*). *This affords a means of finding the rough* A.W. of a *solid* element.

9. A.W. = Equivalent × Valency.

10. *The* Valency *of an element is the number of atoms of hydrogen with which one atom of the element will combine*; it must, of course, be a whole number.

11. Hence, in determining the A.W. of an element, we often

(*a*) Find the equivalents accurately.

(*b*) Find the *approximate* A.W. by Dulong and Petit's Law, §8.

(*c*) Divide the approximate A.W. by the equivalent; the result is the *approximate* valency.

(*d*) Take the *nearest whole number* to the approximate valency to be the *true* valency.

(*e*) Multiply the accurate equivalent by the true valency. The result is the accurate atomic weight.

12. Practically, it is found that *the A.W. of an element is the smallest weight of it ever present in the M.W. of any of its compounds.* Hence a further method of determining the A.W. of an element is to take a large number of compounds of the element, (*a*) find their M.W., (*b*) analyse them quantitatively, and (*c*) calculate the smallest weight of the element present in the M.W. of any of them.

If we take a sufficiently large number of compounds, we shall probably include at least one the molecule of which contains only *one* atom of the element. In this case, the weight of the element in the M.W. of the compound must be its atomic weight.

EXAMPLES.

A. **Molecular Weights.**

(i) A glass globe, evacuated, weighed 58·645 gm. The same globe filled with a certain gas weighed 59·137 gm., while filled with hydrogen at the same temperature and pressure it weighed 58·659 gm. Calculate the vapour density and molecular weight of the gas.

$$\text{V.D.} = \frac{\text{Weight of a known volume of the gas}}{\text{Weight of the same volume of hydrogen}}$$

$$= \frac{59{\cdot}137 - 58{\cdot}645}{58{\cdot}659 - 58{\cdot}645}$$

$$= \frac{0{\cdot}492}{0{\cdot}014} = \underline{35{\cdot}2.}$$

The molecular weight is twice the V.D., i.e. 70·4.

7. *The* Atomic Weight *of an element is the number of times its atom is as heavy as an atom of hydrogen.* The atomic weights of oxygen, hydrogen, nitrogen, chlorine, carbon, sulphur, sodium, potassium, and calcium should be memorized, though in most examinations the required atomic weights are given.

O = 16 (this is the conventional method of expressing the sentence, 'The atomic weight of oxygen is 16'); H = 1; N = 14; Cl = 35·5; C = 12; S = 32; Na = 23; K = 39; Ca = 40.

8. The atomic weight of a solid element multiplied by its specific heat is approximately 6·4 (Dulong and Petit's Law). This affords a means of finding the *rough* A.W. of a solid element.

9. A.W. = Equivalent × Valency.

10. *The* Valency *of an element is the number of atoms of hydrogen with which one atom of the element will combine*; it must, of course, be a whole number.

11. Hence, in determining the A.W. of an element, we often

(*a*) Find the equivalents accurately.

(*b*) Find the *approximate* A.W. by Dulong and Petit's Law, §8.

(*c*) Divide the approximate A.W. by the equivalent; the result is the *approximate* valency.

(*d*) Take the *nearest whole number* to the approximate valency to be the *true* valency.

(*e*) Multiply the accurate equivalent by the true valency. The result is the accurate atomic weight.

gm. in 15 c.c. water, and a depression 18·6 ° is caused in 100 gm. water by $\frac{0{\cdot}645 \times 18{\cdot}6 \times 100}{1{\cdot}20 \times 15}$ gm.

$$\therefore \text{M.W.} = \frac{0{\cdot}645 \times 18{\cdot}6 \times 100}{1{\cdot}20 \times 15}$$
$$= \underline{66{\cdot}7}.$$

Or, using the formula,

$$\text{M.W.} = \frac{w \times K \times 100}{t \times s}$$
$$= \frac{0{\cdot}645 \times 18{\cdot}6 \times 100}{1{\cdot}20 \times 15},$$

which is the same expression as before.

B. **Atomic Weights.**

(iv) The equivalent of copper is 31·8. Its specific heat is 0·094. Find its atomic weight.

$\frac{6{\cdot}4}{0{\cdot}094} = 68$. Hence, by Dulong and Petit's Law, the A.W. is *about* 68.

$\frac{68}{31{\cdot}8} = 2{\cdot}1$, $\therefore$ valency is *about* 2·1 and so must be 2.

$$\therefore \text{A.W.} = 31{\cdot}8 \times 2 = \underline{63{\cdot}6}.$$

(v) 2·16 gm. of silver yielded 2·87 gm. of silver chloride. The specific heat of silver is 0·057. Calculate its atomic weight. [Cl = 35·5.]

$2{\cdot}87 - 2{\cdot}16 = 0{\cdot}71$

Hence 0·71 gm. chlorine = 2·16 gm. silver.

$\therefore$ 35·5 gm. chlorine (equivalent) $= \frac{2{\cdot}16 \times 35{\cdot}3}{9{\cdot}71}$

$= 108$ gm. silver.

Hence equivalent of silver = 108.

$\frac{6{\cdot}4}{0{\cdot}057} = 112$ (approximate A.W.).

$\frac{112}{108} =$ about 1 (approximate valency),

$\therefore$ true valency = 1.

$$\therefore \text{A.W.} = 108 \times 1 = \underline{108}.$$

(ii) In a Victor Meyer experiment, the following data were obtained:

Weight of liquid, 0·247 gm. Volume of air displaced, 24·0 c.c. Barometric pressure, 745 mm. Temperature 14° C. The air was collected over water.

Calculate the vapour density and molecular weight of the liquid.

Water vapour pressure at 14° C. = 12·0 mm.

∴ true pressure on air = 745 − 12 = 733 mm.

Original temperature = 14° C. = 287° Absolute.

∴ volume of air at N.T.P.

$$= \frac{24 \times 273 \times 733}{287 \times 760}$$

$$= 22·0 \text{ c.c.}$$

Weight of this volume of hydrogen at N.T.P.

$$= \frac{0·09 \times 22}{1000}$$

$$= 0·00198 \text{ gm.}$$

∴ V.D. of liquid $= \frac{0·247}{0·00198}$

$= \underline{125}.$

∴ M.W. of liquid $= 125 \times 2 = \underline{250}.$

(iii) In a determination of the molecular weight of a substance by the freezing-point (cryoscopic) method, the following results were obtained:

Weight of substance taken	= 0·645 gm. (w)
Volume of water used as solvent	= 15 c.c.
∴ weight " " " "	= 15 gm. (S)
Depression of the freezing-point	= 1·20° (t)
K *for* 100 gm. water	= 18·6° (K)

If a depression 1·20° is caused by 0·645 gm. in 15 c.c. water, then a depression 18·6° is caused by $\frac{0·645 \times 18·6}{1·20}$

following densities and percentage compositions by weight:

Methyl bromide	V.D. 47·5	Bromine, 84·21 per cent
Ethylene bromide	V.D. 94	Bromine, 85·11 „ „
Tin bromide	V.D. 219	Bromine, 73·06 „ „
Ethyl bromide	V.D. 54·5	Bromine, 73·40 „ „
Tribromopropane	V.D. 140·5	Bromine, 85·41 „ „

What is the probable A.W. of bromine?

First, find the M.W. of each compound, and then calculate the number of parts by weight of bromine in the M.W.:

Methyl bromide V.D. = 47·5 ∴ M.W. = 95.

100 parts by weight of methyl bromide contain 84·21 of bromine,

∴ 95 parts by weight of methyl bromide contain $\frac{84\cdot21 \times 95}{100}$ of bromine.

= 80 parts by weight of bromine.

Ethylene bromide V.D. = 94 ∴ M.W. = 188

∴ parts by weight of bromine in M.W. = $\frac{85\cdot11 \times 188}{100}$

= 160 parts.

Tin bromide. V.D. = 219 ∴ M.W. = 438

∴ parts by weight of bromine in M.W. = $\frac{438 \times 73\cdot06}{100}$

= 320 parts.

Ethyl bromide. V.D. = 54·5 ∴ M.W. = 109

∴ parts by weight of bromine in M.W. = $\frac{109 \times 73\cdot40}{100}$

= 80 parts.

Tribromopropane. V.D. = 140·5 ∴ M.W. = 281

∴ parts by weight of bromine in M.W. = $\frac{281 \times 85\cdot41}{100}$

= 240 parts.

(vi) The equivalent of gold (Au) is 65·7, and its specific heat is 0·032. What will be the formula for gold chloride, and what is the atomic weight of gold?

The formula for gold chloride will be $AuCl_x$, where x is the valency of gold (since chlorine is univalent).

$\frac{6·4}{0·032} = 200$ (approximate A.W.)

$\frac{200}{65·7} =$ about 3 (approximate valency).

$\therefore$ true valency $= 3$, and the formula for gold chloride is $AuCl_3$.

Also, A.W. $= 65·7 \times 3 =$ <u>197·1</u>.

(vii) The following table shows the molecular composition of 10 compounds of carbon. What is the probable atomic weight of carbon?

Compound	Molecular Weight	Parts of Weight of C in Molecular Weight
Methane . .	16	12
Ethane . .	30	24
Acetylene . .	26	24
Ethylene . .	28	24
Carbon dioxide .	44	12
Carbon monoxide .	28	12
Benzene . . .	78	72
Carbon disulphide .	76	12
Chloroform . .	119·5	12
Propyl alcohol .	60	36

The smallest weight of carbon in the M.W. of any of the above compounds is 12; hence the probable A.W. of carbon is 12.

(viii) Certain compounds of bromine have the

7. In a Victor Meyer vapour density determination, 0·247 gm. of a liquid was taken, and the air displaced, measured over water at 745 mm. and 14° C., was found to occupy 24·0 c.c. Calculate the vapour density and molecular weight of the liquid, assuming that 1 litre of hydrogen at N.T.P. weighs 0·09 gm.

8. In a Victor Meyer determination of the vapour density of chloroform, 0·187 gm. of the liquid was taken, and the volume of displaced air (collected over water at 15° C. 752·8 mm.) was 38 c.c. Calculate the molecular weight of chloroform, assuming that 1 litre of hydrogen weighs 0·09 gm. at N.T.P.

9. 0·120 gm. of benzene, a volatile liquid with a molecular weight of 78, was vaporized. If the vapour was measured dry at 200° C. 730 mm., what volume did it occupy? [G.M.V. = 22·4 litres.]

[In questions 10–15 inclusive, K = the depression of the freezing-point, in Centigrade degrees, caused by dissolving the G.M.W. of the solute in 100 gm. solvent.]

10. In a freezing-point molecular weight determination, it was found that 2·0 gm. of the substance dissolved in 100 c.c. of water gave a solution freezing at − 0·186° C. What is the M.W. of the substance? [K = 18·6.]

11. Calculate the M.W. of a substance from the following data: 0·355 gm. of the substance dissolved in 15·0 c.c. of water produced a depression of the freezing-point of 0·27°. [K = 18·6.]

12. When 0·190 gm. of common salt is dissolved in 20 c.c. of water, what depression of the freezing-point

Hence the parts by weight of bromine in the molecular weights of the above compounds are, respectively, 80, 160, 320, 80, and 240.

Therefore the probable A.W. of bromine is 80.

PROBLEMS.

1. 1 litre of chlorine weighs 35·5 times as much as 1 litre of hydrogen at the same temperature and pressure. What are (*a*) the vapour density of chlorine and (*b*) its molecular weight?

2. The formula of hydrogen sulphide is H_2S. Supposing that the volumes of both gases are measured at the same temperature and pressure, how many times as heavy as 1 cubic foot of hydrogen is 1 cubic foot of hydrogen sulphide?

3. 1 litre of hydrogen at N.T.P. weighs 0·09 gm. If 1 litre of ammonia at N.T.P. weighs 0·765 gm., what is the molecular weight of ammonia?

4. The molecular weight in grams of all gases at N.T.P. occupies 22·4 litres. 1·32 gm. of carbon dioxide at N.T.P. occupies 672 c.c. Find the molecular weight of the gas.

5. Write down the molecular weights of the following substances: (*a*) helium, He, (*b*) ozone, O_3, (*c*) hydrogen chloride, HCl, (*d*) aniline, C_6H_7N, (*e*) cane-sugar (sucrose), $C_{12}H_{22}O_{11}$, (*f*) Epsom salt, $MgSO_4 . 7H_2O$.

6. 100 c.c. of a gas at 24° C. 740 mm. weigh 0·26 gm. Calculate its molecular weight, assuming that the G.M.V. of a gaseous substance is 22·4 litres at N.T.P.

22. 0·48 gm. of oxygen combine with 6·0 gm. of a metal. The valency of the metal is 2. Calculate its atomic weight.

23. Two chlorides of an element contain respectively 67·2 and 57·7 of chlorine. Calculate the equivalent of the element in each chloride, and suggest a probable value for its atomic weight.

24. 2·6000 gm. of a non-metallic element is found to combine with hydrogen to form 2·6325 gm. of a gaseous hydride. In many respects, the element closely resembles chlorine, and its hydride closely resembles hydrogen chloride. What is the probable atomic weight of the element?

25. The specific heat of a metallic element, M, is 0·054. The metal forms a volatile chloride, 276·4 c.c. of the vapour of which, measured at 220° C. 770 mm., weigh 1·80 gm. Calculate the exact atomic weight of the element and write the formula of its chloride.

26. The molecular weights of several gaseous or volatile compounds of nitrogen are as follows:

Ammonia, 17; nitrous oxide, 44; hydrocyanic acid, 27; cyanogen, 52; methylamine, 31.

The percentages by weight of nitrogen in these compounds are, respectively: Ammonia, 82·35; nitrous oxide, 63·63; hydrocyanic acid, 51·85; cyanogen, 53·85; methylamine, 45·16.

Calculate the probable atomic weight of nitrogen.

27. The vapour densities of certain gaseous or volatile compounds of chlorine, together with the

would you expect to observe? The actually observed depression was 0·604°. Calculate the apparent M.W. of the salt. [K = 18·6.]

13. 0·466 gm. of resorcinol was dissolved in 18 gm. of benzene. The depression of the freezing-point so produced was 1·15°. Calculate the M.W. of resorcinol. [K = 49.]

14. 1·06 gm. of a solid in 103 gm. of benzene gave a freezing-point depression of 0·61°. Calculate the M.W. of the solid. [K = 49.]

15. 0·042 gm. of metallic potassium was dissolved in 50 gm. of mercury. The depression of the freezing-point of the mercury was observed to be 0·092° C. Find the molecular weight of potassium. [K = 425.]

16. The specific heat of copper is 0·09. Calculate its approximate atomic weight.

17. The specific heat of lead is 0·031. Find a rough value for its atomic weight.

18. The equivalent of a metal is 31·8 and its specific heat is approximately 0·1. What is its atomic weight?

19. The equivalent of a metallic element is 108, and its specific heat is 0·056. What is its atomic weight?

20. 0·667 gm. of a metal yielded 1·000 gm. of its oxide. The specific heat of the metal was 0·066. Calculate its equivalent, valency, and atomic weight.

21. A metallic chloride contains 34·47 per cent of metal. The specific heat of the metal is 0·11. Calculate the equivalent, valency, and atomic weight of the metal, and write the formula for its chloride. (Use the symbol X for one atom of the metal.)

CHAPTER V

FORMULAE AND COMPOSITION BY WEIGHT

1. *The* **Empirical Formula** *of a substance is the formula that shows the atoms of the constituent elements in the simplest numerical ratio*; it may, or may not, be the same as the true, molecular, formula, but the latter is always some whole number multiple of the empirical formula. Thus the empirical formula of steam is H_2O, and this is also the molecular formula; but the molecular formula of glucose is $C_6H_{12}O_6$, while the empirical formula for this substance is CH_2O. Acetic acid has the same empirical formula, viz. CH_2O, and so has lactic acid, but the molecular formulae of these compounds are, respectively, $C_2H_4O_2$ and $C_3H_6O_3$. Note that $C_2H_4O_2$, $C_3H_6O_3$ and $C_6H_{12}O_6 = CH_2O \times 2$, $CH_2O \times 3$ and $CH_2O \times 6$. The gas formaldehyde has the empirical formula CH_2O, and this is also its true formula.

2. To get the true formula, when the empirical formula has been found, it is usual to determine the molecular weight of the substance. Thus, if a substance has the empirical formula CH_2O, its true formula must be CH_2O, $C_2H_4O_2$, $C_3H_6O_3$, $C_4H_8O_4$ . . . $C_nH_{2n}O_n$, where n is a whole number. But the M.W. of a substance whose true formula is CH_2O is (12 + 2

respective percentage weights of chlorine in the compounds, are as follows:

Compound	Vapour density	Percentage weight of chlorine in compound
Hydrogen chloride	18·25	97·26
Chlorine monoxide	43·5	81·61
Chlorine peroxide	33·75	52·59
Sulphur chloride	67·5	52·59
Stannic chloride	130·0	54·61

Find the probable atomic weight of chlorine.

numbers of atoms of the elements present in the molecule.

(*c*) Since atoms are indivisible, this ratio must be reduced to the simplest whole number ratio (by dividing each quotient by the H.C.F. of all the quotients).

(*d*) The simplest whole number ratio of the atoms of the various elements gives us the simplest or empirical formula for the compound.

5. From the empirical formula the true formula may then be calculated if the necessary data (see § 2) are provided.

EXAMPLES.

(i) The empirical formula of aniline is C_6H_7N. What weight of nitrogen is present in 10 gm. aniline?

$(6 \times 12) + 7 + 14$, i.e. 93, gm. aniline contain 14 gm. nitrogen,

$\therefore$ 10 gm. „ „ $\dfrac{14 \times 10}{93}$

$= 1{\cdot}51$ gm. nitrogen.

(ii) Calculate the percentage composition by weight of a substance with the empirical formula $H_2S_2O_7$.

$2 \times 1 + 2 \times 32 + 7 \times 16$, i.e. 178, gm. contain

(*a*) 2 gm. hydrogen,
(*b*) 64 gm. sulphur,
(*c*) 112 gm. oxygen.

$\therefore$ 100 gm. contain $\dfrac{2 \times 100}{178}$ gm.

$= 1{\cdot}12$ gm. hydrogen.

and 100 gm. contain $\dfrac{64 \times 100}{178}$

$= 35{\cdot}96$ gm. sulphur.

$+ 16) = 30$, while that of a substance $C_2H_4O_2$ is 30×2, that of a substance $C_3H_6O_3$ is 30×3, and so on. Hence if the molecular weight is known (or if data are given from which the M.W. may be calculated), the true formula can be calculated from the empirical formula. For example, the empirical formula of hydrogen peroxide is HO, but its M.W. is 34; now $HO = 17$,

$$\therefore \text{the true formula is } HO \times \frac{34}{17} = H_2O_2.$$

3. The composition by weight of a substance can be calculated from its *empirical formula*. Thus, if the empirical formula of a substance is C_3H_8O, we know from the atomic weights that $3 \times 12 + 8 \times 1 + 16$, i.e. 60, parts by weight of it contain 36 parts by weight of carbon, 8 of hydrogen, and 16 of oxygen. This composition by weight may be calculated as a percentage or in any other desired form. For instance, in the compound just given, since 60 parts by weight contain 36 parts by weight of carbon, the percentage by weight of carbon in it is $\frac{36 \times 100}{60} = 60$, the percentage of oxygen $\frac{16 \times 100}{60} = 26{\cdot}67$, and that of hydrogen $13{\cdot}33$.

4. Conversely, from the composition by weight of a substance (whether expressed as a percentage or otherwise), the empirical formula may be calculated as follows:

(*a*) Divide the weight of each element present by the atomic weight of the element.

(*b*) The quotients will be in the same ratio as the

Calculate its empirical formula. [Na = 23; S = 32; H = 1; O = 16.]

$$\frac{20{\cdot}73}{23} = 0{\cdot}9$$

$$\frac{14{\cdot}41}{32} = 0{\cdot}45$$

$$\frac{64{\cdot}86}{18} = 3{\cdot}6$$

$\therefore$ Na : S : H_2O as 0·9 : 0·45 : 3·6, i.e. as 2 : 1 : 8.

$\therefore$ empirical formula is $\underline{Na_2S.8H_2O}$.

(vi) A compound was found to consist of carbon, 26·44 per cent, hydrogen, 3·08 per cent, and bromine, 70·48 per cent. Its vapour density was 227. Find its true formula. [C = 12; H = 1; Br. = 80.]

$$\frac{26{\cdot}44}{12} = 2{\cdot}20$$

$$\frac{3{\cdot}08}{1} = 3{\cdot}08$$

$$\frac{70{\cdot}48}{80} = 0{\cdot}88$$

$\therefore$ C : H : Br as 2·2 : 3·08 : 0·88.

The H.C.F. of 2·2, 3·08 and 0·88 is 0·44.

Dividing each by 0·44 we get 5, 7, and 2.

$\therefore$ C : H : Br as 5 : 7 : 2.

$\therefore$ empirical formula is $C_5H_7Br_2$.

The V.D. is 227, $\therefore$ M.W. = 454.

M.W. of $C_5H_7Br_2$ = (60 + 7 + 160) = 227.

227 is half 454.

$\therefore$ true formula must be twice empirical formula, i.e. *true formula* is $\underline{C_{10}H_{14}Br_4}$.

(vii) On analysis, 4·80 gm. of a substance was found to contain 1·92 gm. of carbon, 2·56 gm. of oxygen,

The rest must be oxygen; i.e. $(100 - 1{\cdot}12 - 35{\cdot}96)$
$= 72{\cdot}92$ gm.

$\therefore$ percentage composition by weight is
<u>1·12 hydrogen, 35·96 sulphur, 72·92 oxygen.</u>

(iii) Acetylene contains 92·3 per cent of carbon and 7·7 per cent of hydrogen. What is its empirical formula? [C = 12; H = 1.]

$$\frac{92{\cdot}3}{12} = 7{\cdot}7$$
$$\frac{7{\cdot}7}{1} = 7{\cdot}7$$

$\therefore$ ratio of carbon atoms to hydrogen atoms is 7·7 : 7·7, i.e. 1 : 1.

Hence empirical formula of acetylene is <u>CH.</u>

(iv) ·3 gm. of calcium carbonate were found to consist of 1·2 gm. of calcium, 0·36 gm. of carbon and 1·44 gm. of oxygen. Find the empirical formula of calcium carbonate. [Ca = 40; C = 12; O = 16.]

$$\frac{1{\cdot}2}{40} = 0{\cdot}03$$
$$\frac{0{\cdot}36}{12} = 0{\cdot}03$$
$$\frac{1{\cdot}44}{16} = 0{\cdot}09$$

$\therefore$ Ca : C : O as 0·03 : 0·03 : 0·09, i.e. as 1 : 1 : 3.

$\therefore$ empirical formula of calcium carbonate is <u>$CaCO_3$.</u>

(v) A sulphide of sodium, containing water of crystallization, gave the following results on analysis:

Sodium, 20·73 per cent.

Sulphur, 14·41 per cent.

Water, 64·86 per cent.

4. A compound has the following percentage composition by weight: C 20; H 6·7; N 46·7; O 26·6. Its molecular weight is 60. What is its true formula?

5. A compound gave the following results on analysis: 1·670 gm. gave 1·257 gm. silver and 0·413 gm. chlorine. The molecule of the substance contains one atom of chlorine. Calculate the true formula of the substance.

6. A compound of carbon, hydrogen, and bromine was found to contain 11·53 per cent carbon and 1·92 per cent hydrogen. Its vapour density is 104. What is its true formula?

7. A litre of hydrogen at N.T.P. weighs 0·09 gm. A litre of a certain gas, under the same conditions of temperature and pressure, was found to weigh 1·395 gm. On analysis, the percentage composition of the gas proved to be C 38·7; H 16·1; and N 45·2. Find the true formula of the gas.

and 0·32 gm. of hydrogen. Its molecular weight is 120. What is its true formula?

$$\frac{1{\cdot}92}{12} = 0{\cdot}16$$

$$\frac{2.56}{16} = 0{\cdot}16$$

$$\frac{0{\cdot}32}{1} = 0{\cdot}32$$

$\therefore$ C : O : H as 0·16 : 0·16 : 0·32 = 1 : 1 : 2

$\therefore$ empirical formula is COH_2.

But M.W. is 120, while $COH_2 = 12 + 16 + 2 = 30$.

$\therefore$ true formula is 4 times the empirical formula, and is thus $\underline{C_4O_4H_8}$.

PROBLEMS.

1. Calculate the percentage compositions by weight of the following substances:

(i) Potassium chlorate, $KClO_3$.
(ii) Sodium carbonate, Na_2CO_3.
(iii) Hydrogen chloride, HCl.
(iv) Ammonium carbonate, $(NH_4)_2CO_3$.

2. Calculate the empirical formulae of substances with the following percentage compositions by weight:

(i) Ca 54·1; O 43·2; H 2·7.
(ii) Ca 40; C 12; O 48.
(iii) Fe 63·6; S 36·4.
(iv) K 39; H 1; C 12; O 48.
(v) K 38·6; N 13·9; O 47·5.

3. Calculate the empirical formulae of substances with the following percentage compositions by weight:

(i) Na 43·4; C 11·3; O 45·3.
(ii) Cu 25·6; S 12·8; O 25·6; H_2O 36·0.
(iii) Zn 22·7; S 11·1; O 22·2; H_2O 44·0.
(iv) Pb 90·66; O 9·34.
(v) K 26·53; Cr 35·37; O 38·10.

EXAMPLES.

(i) What weight of hydrogen is required to react with 10·0 gm. of chlorine to form hydrogen chloride?

$$H_2 + Cl_2 = 2HCl.$$

The atomic weight of hydrogen is 1; that of chlorine is 35·5.

$\therefore$ since 1 molecule of chlorine ≡ 1 molecule of hydrogen

2 × 35·5 gm. „ „ ≡ 2 gm. „ „

$\therefore$ 10 gm. „ „ $\equiv \frac{2 \times 10}{2 \times 35 \cdot 5}$

$= \underline{0 \cdot 282 \text{ gm.}}$

(ii) What weight of sulphuric acid is required to neutralize 5 lb. of potassium hydroxide?

$$2KOH + H_2SO_4 = K_2SO_4 + 2H_2O.$$

[K = 39; S = 32; O = 16; H = 1.]

From the equation, it is seen that one molecule of sulphuric acid is required for 2 molecules of potassium hydroxide.

Therefore 2 molecular weights, in lb., of potassium hydroxide require 1 molecular weight, in lb., of sulphuric acid.

But M.W. of potassium hydroxide $= 39 + 16 + 1 = 56$,

and M.W. of sulphuric acid $= 2 \times 1 + 32 + 4 \times 16 = 98$.

$\therefore$ 112 lb. of potassium hydroxide ≡ 98 lb. of sulphuric acid

$\therefore$ 5 lb. „ „ „ $\equiv \frac{98 \times 5}{112}$ lb. „ „

$= \underline{4 \cdot 38 \text{ lb.}}$

(iii) Calculate the weight of sodium bicarbonate required to yield 300 c.c. of carbon dioxide at N.T.P. (a)

CHAPTER VI

REACTING QUANTITIES FROM EQUATIONS

1. An equation tells us (*a*) the relative *weights* of the reacting substances, and (*b*) the relative *volumes* of the reacting substances, if *gaseous*, and of the products, if *gaseous*.

2. The **Gram-Molecular-Weight** ('G.M.W.'), that is, the M.W. in grams, of any gas occupies 22·4 litres at N.T.P.

In other words:

The **Gram-Molecular-Volume** (i.e. volume occupied by G.M.W.) of any gas is 22·4 litres at N.T.P.

[N.B.—The G.M.V. is 22·4 litres at N.T.P. when the standard of atomic weights is O = 16·000. On this standard the atomic weight of hydrogen is 1·008, not 1·000, and the weight of hydrogen occupying 22·4 litres at N.T.P. is 2·016 gm. If the atomic weight of hydrogen is taken as exactly 1·000, then the G.M.V. of a gaseous substance at N.T.P. is 22·22 litres. Unless you are given such definite information in the question as: '1 litre of hydrogen at N.T.P. weighs 0·09 gm.' or, '1 gm. of hydrogen at N.T.P. occupies 11·11 litres,' always take the G.M.V. as 22·4 litres at N.T.P.]

3. Where no atomic weights are given, use the approximate values given on p. 129.

liberate 8 tons of hydrogen from (*a*) dilute sulphuric acid, (*b*) dilute hydrochloric acid?

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$
$$Zn + 2HCl = ZnCl_2 + H_2.$$

4. What weight of potassium nitrate must be used to produce 126 lb. of nitric acid according to the reaction:

$$KNO_3 + H_2SO_4 = KHSO_4 + HNO_3.$$

Would a greater or a less weight of sodium nitrate, $NaNO_3$, be required?

5. How many grams of chlorine are contained in 100 gm. of common salt, NaCl?

6. Which contains the greater weight of nitrogen: 100 gm. of nitrous oxide (N_2O) or 100 gm. of nitric oxide (NO)?

7. When barium chloride crystals, $BaCl_2.2H_2O$, are heated, all the water of crystallization is driven off. What percentage loss in weight occurs?

8. When sodium bicarbonate is heated, it decomposes according to the equation:

$$2NaHCO_3 = Na_2CO_3 + H_2O + CO_2.$$

What loss in weight would occur if 100 gm. of sodium bicarbonate were heated till the above reaction was complete?

9. If sugar, $C_{12}H_{22}O_{11}$, is heated with concentrated sulphuric acid, all the carbon in it is set free. What weight of carbon would be obtained from 68·4 gm. of sugar?

by the action of heat, (b) by the action of dilute hydrochloric acid.

$$\text{Heat: } 2NaHCO_3 = Na_2CO_3 + H_2O + CO_2.$$

Action of hydrochloric acid:

$$NaHCO_3 + HCl = NaCl + H_2O + CO_2.$$

(*a*) 2 G.M.W.s of sodium bicarbonate yield 1 G.M.V. of carbon dioxide at N.T.P.

i.e. $2 \times (23 + 1 + 12 + 3 \times 16)$ gm. $NaHCO_3$
= 22,400 c.c. CO_2 at N.T.P.

or 168 gm. $NaHCO_3$ = 22,400 c.c. CO_2 at N.T.P.

If 22,400 c.c. CO_2 are yielded by 168 gm. $NaHCO_3$,

300 c.c. CO_2 „ „ „ $\dfrac{168 \times 300}{22{,}400}$

= 2·25 gm. sodium bicarbonate.

(*b*) From the equations, it is clear that, by the action of a dilute acid, a given weight of sodium bicarbonate yields twice as much carbon dioxide as it does when heated. Hence the answer to the second part of the question is $\dfrac{2\cdot 25}{2}$ i.e. 1·125 gm. sodium bicarbonate.

PROBLEMS.

1. What weight of oxygen is required to react with 4 gm. of hydrogen to form water?

$$2H_2 + O_2 = 2H_2O.$$

2. If 24 gm. of oxygen is converted into ozone, O_3, what weight of the latter gas will be obtained?

3. How many tons of zinc would be necessary to

measured at N.T.P., liberated by the action of sulphuric acid on 29·25 gm. of common salt.

$$NaCl + H_2SO_4 = NaHSO_4 + HCl.$$

16. A solution of sodium chloride contains 5 gm. of NaCl per litre. What weight of silver chloride would be precipitated from 100 c.c. of this solution by the addition of excess of silver nitrate solntion?

$$NaCl + AgNO_3 = AgCl \downarrow + NaNO_3.$$

17. 10 tons of a sample of iron pyrites, FeS_2, are roasted in air so that all the sulphur is converted into sulphur dioxide. The latter is then completely converted into sulphuric acid. What weight of the acid is obtained?

18. What weight of carbon monoxide is necessary to reduce 16 gm. of ferric oxide to metallic iron?

$$Fe_2O_3 + 3CO = 2Fe + 3CO_2.$$

19. What is the maximum weight of calcium carbonate that could be formed by adding 53 lb. of anhydrous sodium carbonate to permanently hard water (i.e. water containing calcium sulphate)?

$$CaSO_4 + Na_2CO_3 = Na_2SO_4 + CaCO_3.$$

20. 10 gm. of ammonia gas are mixed with 10 gm. of hydrogen chloride. What weight of ammonium chloride will be formed? Which gas will be in excess, and how many grams of it will be left over?

$$NH_3 + HCl = NH_4Cl.$$

21. A certain white solid is known to be either

10. When calcium carbonate, $CaCO_3$, is strongly heated, a residue of calcium oxide is obtained:

$$CaCO_3 = CaO + CO_2.$$

On treating calcium oxide with water, it is converted into calcium hydroxide:

$$CaO + H_2O = Ca(OH)_2.$$

What weight of calcium hydroxide could be obtained from 200 gm. of calcium carbonate?

11. By the action of heat on potassium chlorate, oxygen is set free:

$$2KClO_3 = 2KCl + 3O_2.$$

What weight of oxygen would be given by 10 gm. of the chlorate?

12. What weight of manganese dioxide is necessary to set free 213 gm. of chlorine from hydrochloric acid?

$$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2.$$

13. How much ammonium nitrate must be heated to yield 100 gm. of nitrous oxide?

$$NH_4NO_3 = N_2O + 2H_2O.$$

14. If copper sulphate crystals, $CuSO_4.xH_2O$, are carefully heated, the anhydrous sulphate, $CuSO_4$, is left. 10 gm. of the crystals, when so heated, gave 6·4 gm. of the anhydrous sulphate. What is the value of x?

15. At N.T.P., 36·5 gm. of hydrogen chloride occupy 22·4 litres. Find the volume of hydrogen chloride,

27. A specimen of cupric oxide is contaminated with metallic copper. On reducing in a current of hydrogen, 1·25 gm. of the specimen gave 1·049 gm. copper. Find the percentage by weight of cupric oxide in it.

28. The secretary of the lawn tennis club bought 1 ton of lawn sand, consisting of a mixture of ammonium sulphate, ferrous sulphate, and sand. The mixture was supposed to contain 45 per cent of ammonium sulphate. 10 gm. of it, when boiled with excess of caustic soda, yielded 1·05 gm. ammonia. Was the percentage of ammonium sulphate in the lawn sand correct, or incorrect? If the latter, how many lb. too little or too much were there in the ton of mixture?

29. When magnesium carbonate is heated, magnesium oxide is left:

$$MgCO_3 = MgO + CO_2.$$

What volume of sulphuric acid solution, containing 20 gm. H_2SO_4 per litre, would be required to convert into magnesium sulphate, $MgSO_4$, the magnesium oxide obtained by heating 100 gm. of magnesium carbonate?

30. *Aniline*, C_6H_7N, *reacts with bromine*, Br_2, *in* the proportion of one molecule of aniline to three molecules of bromine. The density of bromine is 3·2, i.e. 1 c.c. of it weighs 3·2 gm. What volume of bromine is required to react completely with 10 gm. of aniline?

potassium chlorate or sodium chlorate. 1·00 gm. of it, on heating, gave 0·392 gm. of oxygen. Is it the sodium salt or the potassium salt?

22. Six specimens of pure sodium hydroxide, $NaOH$, each weighing 10 gm., are converted completely into (*a*) sodium chloride, $NaCl$, (*b*) sodium bromide, $NaBr$, (*c*) sodium nitrate, $NaNO_3$, (*d*) sodium nitrite, $NaNO_2$, (*e*) sodium carbonate, Na_2CO_3, and (*f*) sodium bicarbonate, $NaHCO_3$. Calculate the weight of each product.

23. A solution of sodium sulphate contains 5 gm. Na_2SO_4 per litre. 200 c.c. of this solution are mixed with excess of barium chloride solution. What weight of barium sulphate will be precipitated?

24. 12·6 gm. of crystalline oxalic acid, $H_2C_2O_4.2H_2O$, is heated with concentrated sulphuric acid until completely decomposed according to the equation:

$$H_2C_2O_4.2H_2O = 3H_2O + CO + CO_2.$$

Calculate (*a*) the weight of carbon monoxide formed, and (*b*) the weight of the precipitate that would be obtained if the whole of the carbon dioxide were passed into excess of lime-water.

25. How many grams of sodium hydroxide are required to convert 20 gm. of sodium hydrogen sulphate, $NaHSO_4$, into sodium sulphate, Na_2SO_4? What weight of the latter would be formed?

26. 6·69 gm. of lead monoxide, PbO, is heated in a current of hydrogen until it is completely reduced to metal. What weight of lead will be left, and what weight of water will be formed?

37. 22·4 litres of ammonia are split up into nitrogen and hydrogen:

$$2NH_3 = N_2 + 3H_2.$$

Calculate the weight and the volume of each gas so produced. [All volumes to be measured at N.T.P.]

38. (i) 0·42 gm. of sodium bicarbonate is heated to constant weight:

$$2NaHCO_3 = Na_2CO_3 + H_2O + CO_2.$$

(ii) The residual sodium carbonate is then treated with dilute hydrochloric acid:

$$Na_2CO_3 + 2HCl = 2NaCl + H_2O + CO_2.$$

Calculate the volumes, at N.T.P., of the carbon dioxide evolved in reactions (i) and (ii).

39. What volume of chlorine, at N.T.P., could be obtained by acting upon 5 gm. of bleaching-powder with dilute hydrochloric acid?

$$CaOCl_2 + 2HCl = CaCl_2 + H_2O + Cl_2.$$

40. The specific gravity of alcohol is 0·78. If 59 c.c. of alcohol (C_2H_6O) were burned, the carbon in it being converted into carbon dioxide, what volume of the latter gas, measured at N.T.P., would be formed?

41. 28 gm. of iron is dissolved in dilute sulphuric acid. Find the volume of hydrogen evolved, measured at 15° C. 576 mm.

42. Calculate the volumes of oxygen (measured at 27° C. 740 mm.) liberated by the action of heat upon (*a*) 24·5 gm. of potassium chlorate, (*b*) 21·3 gm. of

Reacting volumes of gases from equations.

[N.B. Except where otherwise instructed, assume that the G.M.W. of any gas at N.T.P. occupies 22·4 litres.]

31. What volume of carbon dioxide, at N.T.P., could be obtained from 6 gm. of carbon? Would the volume of carbon monoxide obtainable from the same weight of carbon be equal to, more than, or less than, the volume of carbon dioxide obtainable?

$$C + O_2 = CO_2.$$
$$2C + O_2 = 2CO.$$

32. Find the volume of hydrogen, at N.T.P., obtained by dissolving 10 kilograms of calcium, Ca, in water:

$$Ca + 2H_2O = Ca(OH)_2 + H_2.$$

33. How many c.c. of oxygen, measured at N.T.P., could be obtained by heating 12·25 gm. of potassium chlorate?

$$2KClO_3 = 2KCl + 3O_2.$$

34. 4·5 gm. of water is completely decomposed by electrolysis. Calculate the respective volumes of hydrogen and oxygen obtained, at N.T.P.

35. 3 litres of ozone are treated, to convert the ozone into oxygen. What volume of the latter gas is formed?

$$2O_3 = 3O_2.$$

36. 10 gm. of calcium carbonate is strongly heated. What volume of carbon dioxide, measured at N.T.P., will be given off?

$$CaCO_3 = CaO + CO_2.$$

cupric sulphide the whole of the copper in 15 gm. of copper sulphate crystals, $CuSO_4.5H_2O$?

48. Calculate the volume of carbon monoxide obtained by heating 10 gm. of formic acid with sulphuric acid:

$$H.COOH = H_2O + CO.$$

At the temperature and pressure at which the volume of the gas was measured, 1 litre of hydrogen weighs 0·08 gm.

49. 8 gm. of fused sodium hydroxide is decomposed by electrolysis:

$$2NaOH = 2Na + O_2 + H_2.$$

Calculate the total volume of the oxygen and hydrogen produced, assuming that the measurements were made at 27° C. 700 mm. and that 1 litre of hydrogen at N.T.P. weighs 0·09 gm.

50. In a Victor Meyer vapour density experiment, it was found that 0·233 gm. of a liquid gave sufficient vapour to displace 28·7 c.c. of air, collected over water at 15° C.; the barometer stood at 771 mm. Pressure of aqueous vapour at 15° C. = 13 mm.

(i) Calculate the volume of the air at N.T.P.

(ii) Assuming that 1 litre of hydrogen at N.T.P. weighs 0·09 gm., find the vapour density and molecular weight of the liquid.

(iii) Supposing that the molecule of the substance contains three atoms of carbon, find the weight of carbon dioxide that would be obtained on the combustion of 0·2550 gm. of the substance.

sodium chlorate, $NaClO_3$, (c) 10·1 gm. of potassium nitrate.

[Equation for (c): $2KNO_3 = 2KNO_2 + O_2$.]

43. A specimen of the mineral pyrolusite consisted of manganese dioxide and silica. Silica has no action on hydrochloric acid. On heating 2·00 gm. of the pyrolusite with excess of concentrated hydrochloric acid, 473·8 c.c. chlorine (measured at 12° C. 750 mm.) were evolved. Calculate the percentage by weight of manganese dioxide in the pyrolusite.

44. It is required to obtain 100 litres of acetylene, C_2H_2 (measured at 27° C. 600 mm.), by the action of water on calcium carbide:

$$CaC_2 + 2H_2O = Ca(OH)_2 + C_2H_2.$$

What weight of the carbide must be used?

45. Find the volume of hydrogen chloride (measured at 18° C. 755 mm.) that could be liberated by the action of sulphuric acid on 25 gm. of common salt:

$$NaCl + H_2SO_4 = NaHSO_4 + HCl.$$

46. One litre of hydrogen at N.T.P. weighs 0·09 gm. Calculate the volume of hydrogen (measured at 100° C. 775 mm.) necessary to reduce 1·45 gm. of litharge (PbO) to metallic lead:

$$PbO + H_2 = Pb + H_2O.$$

47. When hydrogen sulphide is passed into copper sulphate solution, cupric sulphide is precipitated:

$$CuSO_4 + H_2S = CuS + H_2SO_4.$$

What volume of hydrogen sulphide (measured at 18° C. 720 mm.) would be required to precipitate as

(*b*) If excess of undissolved solute is *not* present, a supersaturated solution (see 4) may be formed, and too high a value for the solubility might be found.

3. **A saturated solution** is a solution that remains unchanged in the presence of solid solute, neither dissolving any of the latter, nor depositing any more upon it.

4. **A supersaturated solution** contains a larger weight of solute than corresponds to the true solubility. Such a solution cannot exist in presence of undissolved solute, and on adding even a minute crystal of the latter the solution deposits its excess of solute immediately.

5. **A solubility curve** is a graph drawn by plotting the solubilities of a substance in a particular solvent at various temperatures, against the temperatures.

EXAMPLES.

(i) An evaporating dish weighed 28·75 gm. empty. Some saturated common salt solution was poured into it, and the basin and contents were found to weigh 40·63 gm. The solution was then evaporated to dryness, and the basin and residual salt weighed when cool; the weight was 31·91 gm. Calculate the solubility of common salt at the temperature of the experiment.

Weight of basin + solution	= 40·63 gm.
Weight of basin empty	= 28·75 gm.
∴ weight of solution	= 11·88 gm.

CHAPTER VII

SOLUBILITIES AND SOLUBILITY CURVES

1. A solution is a homogeneous mixture of two or more substances, in which one substance is in noticeably greater proportion than the other or others.

If we have a solution consisting of a mixture of two substances, the substance in excess is called the *solvent*, while the other is called the *solute*. Thus if we dissolve some salt in water, the water is the solvent, the salt is the solute, and the resulting liquid is a solution of salt in water.

Broadly speaking, we may describe the solvent as 'the substance that does the dissolving' and the solute as 'the substance dissolved.'

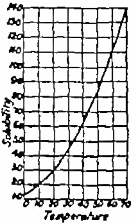
2. **The solubility of a substance** at a particular temperature is the maximum number of grams of it that will dissolve, at that temperature, in 100 gm. of the solvent concerned, in the presence of excess of undissolved solute.

Notes on this definition.

(*a*) Since the solubility of practically all substances in practically all solvents varies with the temperature, it is necessary to say to what temperature any particular figure for the solubility refers.

(a) The curve is shown in the figure. Since the solubilities are given only to the nearest gram (except in one case), there is no need to use minutely squared paper.

(b) The solubility of potassium nitrate at 44° from the curve, is 70.



(c) The solubility of potassium nitrate at 30° is 46, therefore 110 − 46, i.e. 64 gm., of the salt would separate out.

(d) From the curve, the solubility of potassium nitrate is 25 at 15° C.

(e) Since the solubility of potassium nitrate at 40° C. is 64, 100 + 64 gm. of the saturated solution at this temperature contain 64 gm. of the salt.

$\therefore$ 82 gm. of the solution contain $\frac{82 \times 64}{164}$

= 32 gm. of the salt,

and, consequently, 50 gm. of water.

At 0° C., the solubility of potassium nitrate is 13; therefore 50 gm. of water would dissolve 6·5 gm. of the salt.

But the solution that is being cooled contains 32 gm. of the salt per 50 gm. of water,

$\therefore$ 32 − 6·5, i.e. 25·5 gm., would crystallize out.

PROBLEMS.

1. The solubility of sodium chloride in water at various temperatures is given below. Plot the solubility curve.

Temperature °C.	*Solubility in grams*
0	35·8
20	35·9
40	36·5
60	37·2
80	38·0
100	38·7

Weight of basin + salt = 31·91 gm.
Weight of basin empty = 28·75 gm.
∴ weight of salt = 3·16 gm.

∴ weight of water that had dissolved 3·16 gm. salt

$$= 11·88 - 3·16$$
$$= 8·72 \text{ gm.}$$

If 8·72 gm. water dissolve 3·16 gm salt,

then 100 gm. " " $\frac{3·16 \times 100}{8·72}$ gm. salt

$$= 36·3 \text{ gm.}$$

∴ solubility of salt in water at the temperature of the experiment is 36·3 gm.

(ii) In a determination of the solubility of potassium nitrate in water at various temperatures, the results obtained were as follows:

Temp. in °C.	0	10	20	30	40	50	60	70
Solubility (gm. KNO_3 in 100 gm. water).	13	21	31·5	46	64	83	110	140

(*a*) Plot the solubility curve of potassium nitrate from 0° to 70°.

(*b*) Read from the curve the solubility of potassium nitrate at 44°.

(*c*) Suppose that you had a solution of 100 gm. potassium nitrate in 100 gm. of water at 60° C., and you cooled the solution to 30° C. What weight of potassium nitrate would you expect to crystallize out?

(*d*) At what temperature is the solubility of potassium nitrate in water 25?

(*e*) 82 gm. of a solution of potassium nitrate saturated at 40° C. are cooled to 0° C. Calculate the weight of KNO_3 left in the solution.

4. Plot the solubility curve of potassium nitrate in water from the following data:

Temperature °C.	*Solubility in grams*
0	13·3
10	20·9
20	31·6
40	63·9
60	109·9
80	169·0
100	246·0
114	311·0

From your curve, find the solubility of potassium nitrate at (*a*) 15° C., (*b*) 54° C., (*c*) 70° C.

5. Plot the solubility curve of calcium hydroxide in water from the following data:

Temperature °C.	*Solubility in grams*
0	0·185
10	0·176
20	0·165
40	0·141
60	0·116
80	0·094
100	0·077

6. The following figures show the volume of carbon dioxide that will dissolve in one volume of water at various temperatures. Construct a curve from these figures.

Temperature °C.	*Vol. of carbon dioxide dissolved*
0	1·713
5	1·424
10	1·194
15	1·019
20	0·878

If 138·7 gm. of the solution saturated at 100° C. were cooled to 20° C., what weight of crystals should separate?

2. Plot the solubility curve of sodium chlorate from the following data:

Temperature °C.	*Solubility in grams*
0	82
20	99
40	124
60	147
80	176
100	233
120	333

If 100 gm. of the solution saturated at 80° were cooled to 20°, what weight of sodium chlorate crystals would be obtained?

3. Plot the solubility curve of sodium sulphate from the following data:

Temperature °C.	*Solubility in grams*
0	5·0
10	9·0
20	19·4
30	40·0
34	55·0
40	48·8
50	46·7
60	45·3
70	44·4
80	43·7
90	43·1
100	42·5
104	42·2

4. Plot the solubility curve of potassium nitrate in water from the following data:

Temperature °C.	*Solubility in grams*
0	13·3
10	20·9
20	31·6
40	63·9
60	109·9
80	169·0
100	246·0
114	311·0

From your curve, find the solubility of potassium nitrate at (*a*) 15° C., (*b*) 54° C., (*c*) 70° C.

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3. Plot the solubility curve of sodium sulphate from the following data:

Temperature °C.	*Solubility in grams*
0	5·0
10	9·0
20	19·4
30	40·0
34	55·0
40	48·8
50	46·7
60	45·3
70	44·4
80	43·7
90	43·1
100	42·5
104	42·2

4. Plot the solubility curve of potassium nitrate in water from the following data:

Temperature °C.	*Solubility in grams*
0	13·3
10	20·9
20	31·6
40	63·9
60	109·9
80	169·0
100	246·0
114	311·0

From your curve, find the solubility of potassium nitrate at (*a*) 15° C., (*b*) 54° C., (*c*) 70° C.

5. Plot the solubility curve of calcium hydroxide in water from the following data:

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10	0·176
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60	0·116
80	0·094
100	0·077

6. The following figures show the volume of carbon dioxide that will dissolve in one volume of water at various temperatures. Construct a curve from these figures.

Temperature °C.	*Vol. of carbon dioxide dissolved*
0	1·713
5	1·424
10	1·194
15	1·019
20	0·878

Temperature °C.	*Vol of carbon dioxide dissolved*
25	0·759
30	0·665
40	0·530
50	0·436
60	0·359

7. Plot the solubility curve of chlorine in water from the following data:

Temperature °C.	*Solubility in grams*
0	1·46
6	1·08
10	0·98
15	0·84
25	0·64
30	0·57
40	0·46
50	0·39
60	0·33
70	0·28
80	0·22
90	0·13
100	0·00

8. At 14° C., the specific gravity of saturated ammonia solution is 0·884. 10 c.c. of this solution were made up to 200 c.c. with distilled water, and 20 c.c. of the liquid was treated against normal sulphuric acid. It was found that 18·7 c.c. of the latter were required. Calculate the solubility of ammonia in water at 14° C.

CHAPTER VIII

GAS ANALYSIS

1. **Gay-Lussac's Law, or The Law of Gaseous Volumes, or The Law of the Combination of Gases by Volume.**—*When gases react together, the volumes in which they do so are in a simple ratio to one another, and also to the volume of the product if that is gaseous.*

ILLUSTRATIONS.

(*a*) 1 volume of oxygen combines with 2 volumes of carbon monoxide to form 2 volumes of carbon dioxide.

(*b*) 2 volumes of hydrogen combine with 1 volume of oxygen to form liquid water, or, if the temperature is above 100°, 2 volumes of steam.

(*c*) 2 volumes of ammonia, on decomposition by electric sparks, give 1 volume of nitrogen and 3 volumes of hydrogen.

(*d*) 1 volume of ammonia combines with 1 volume of hydrogen chloride to form ammonium chloride (solid).

(*e*) 1 volume of hydrogen combines with 1 volume of chlorine to form 2 volumes of hydrogen chloride (hydrochloric acid gas).

2. **Avogadro's Hypothesis.**—*Equal volumes of all*

gases under the same conditions of temperature and pressure contain the same number of molecules.

Conversely, equal numbers of molecules of gases, at the same temperature and pressure, occupy equal volumes.

3. In the analysis of gas mixtures, carbon dioxide and sulphur dioxide are frequently absorbed by sodium hydroxide solution, carbon monoxide by ammoniacal cuprous chloride solution, and oxygen by alkaline pyrogallol. [*Note* that alkaline pyrogallol will absorb carbon dioxide and sulphur dioxide, so that in analysing e.g. a mixture of carbon dioxide, oxygen, and nitrogen, the volume of carbon dioxide would first be ascertained, by observing the reduction in volume on addition of NaOH solution, and the volume of oxygen (= diminution in volume on shaking with alkaline pyrogallol) would be determined *after the carbon dioxide had been removed.*]

4. Gas analysis is often effected by explosion, or, to use the classical term, by 'eudiometry.' A eudiometer is a graduated tube made of stout glass and closed at one end. Two wires are fixed into the tube, in such a way that a spark can be passed between them through the gas or gases in the tube.

On sparking with oxygen: (*a*) *hydrogen* yields water:

$$2H_2 + O_2 = H_2O;$$

(*b*) *carbon monoxide* yields carbon dioxide:

$$2CO + O_2 = 2CO_2;$$

(*c*) *gaseous hydrocarbons* yield carbon dioxide and

water (below 100° C.) or carbon dioxide and steam (above 100° C.):

$$C_xH_y + (x + \frac{y}{4}) O_2 = x CO_2 + \frac{y}{2} H_2O;$$

(*d*) *ammonia* yields nitrogen and water (below 100°) or steam (above 100°):

$$4NH_3 + 3O_2 = 2N_2 + 6H_2O;$$

(*e*) *nitrogen* remains unchanged under the conditions of the experiment. [Continued sparking will cause some combination, but in eudiometry only one or two sparks are passed—just enough to explode an explosive mixture.]

If air is used to supply the oxygen, it may be taken (in the absence of instructions to the contrary) that the composition of air is 21 per cent oxygen and 79 per cent. nitrogen by volume. This approximation is usually sufficiently close for eudiometric work.

5. **The molecular weight in grams (G.M.W.) of any gas at N.T.P. occupies 22·4 litres.** Alternatively, this may be expressed by saying that **the gram molecular volume (G.M.V.) of any gas at N.T.P. is 22·4 litres.**

Note that, on the oxygen standard of atomic weights (O = 16·000), to which the above figure of 22·4 refers, the atomic weight of hydrogen is 1·008, not 1·000. To occupy 22·4 litres at N.T.P., therefore, 2·016 gm. of hydrogen are required. The difference between the volume of 2 gm. of hydrogen at N.T.P. (22·2 litres) and that of 2·016 gm. (22·4 litres) is not negligible, but, unless you are told to use 22·2 litres as the G.M.V. of

hydrogen (or are given data which come to the same thing, e.g. '1 litre of hydrogen at N.T.P. weighs 0·09 gm.') you should always take the G.M.V. of any gas at N.T.P. as 22·4 litres.

6. **Graham's Law of the Diffusion of Gases.**—*The relative rates of diffusion of gases are inversely proportional to the square roots of their densities.*

$$\text{Or, } \frac{R}{R'} = \frac{\sqrt{D'}}{\sqrt{D}}.$$

EXAMPLES.

(i) The formula of the gaseous compound carbon suboxide is C_3O_2. What would be the weight of 11·2 litres of it at N.T.P.?

The G.M.V. is $3 \times 12 + 2 \times 16 = 68$ gm.
$\therefore$ 68 gm. at N.T.P. occupy 22·4 litres.
$\therefore$ 11·2 litres, which is half 22·4 litres, will weigh 34 gm.

(ii) What would be the volume of 10 gm. of ammonia at N.T.P.?

The formula for ammonia is NH_3; therefore its molecular weight is 17. Hence:

17 gm. ammonia at N.T.P. occupy 22·4 litres,
$\therefore$ 10 gm. „ „ „ „ $\frac{22 \cdot 4 \times 10}{17}$
$= 13 \cdot 2$ litres.

(iii) The molecular weight of a certain gas is 81. How many grams of it would occupy the same volume as 25 gm. of hydrogen chloride, under the same conditions of temperature and pressure?

Since all gases obey the same gas laws, and since the conditions of temperature and pressure are stated to be the same for both gases, it is unnecessary to know what they are.

The molecular weight of hydrogen chloride, HCl, is 36·5. Therefore 81 gm. of the given gas occupy the same volume as 36·5 gm. of hydrogen chloride.

If 36·5 gm. hydrogen chloride occupy the same volume as 81 gm. of the gas,

then 25 gm. hydrogen chloride occupy the same volume as

$$\frac{81 \times 25}{36 \cdot 5}$$

$$= \underline{55 \cdot 5 \text{ gm. of the gas.}}$$

(iv) What volume of nitrogen would be left if an iron wire were heated in 100 c.c. of nitrous oxide and the residual gas brought to the original temperature and pressure?

The iron forms iron oxide, which is a solid; its volume may therefore be neglected.

The effective equation is:

$$N_2O + \text{iron} = N_2 + \text{iron oxide.}$$

1 molecule of nitrous oxide yields 1 molecule of nitrogen.

∴ by Avogadro's Hypothesis,

1 volume of nitrous oxide yields 1 volume of nitrogen.

∴ 100 c.c. of nitrous oxide yield 100 c.c. of nitrogen.

<u>100 c.c. of nitrogen.</u>

(v) What volume of nitrogen would be left if 100 c.c. of nitric oxide (NO) were treated in the same way?

$$2NO + \text{iron} = \text{iron oxide} + N_2.$$

2 molecules of nitric oxide yield 1 molecule of nitrogen.

∴ by Avogadro's Hypothesis,

2 volumes of nitric oxide yield 1 volume of nitrogen.

∴ 100 c.c of nitric oxide yield 50 c.c. of nitrogen.

<u>50 c.c. of nitrogen.</u>

(vi) If 100 c.c. of nitric oxide were split up into nitrogen and oxygen, what would be the volume of the residual mixture?

$$2NO = N_2 + O_2.$$

2 molecules of nitric oxide give 1 molecule of nitrogen and 1 molecule of oxygen.

∴ by Avogadro's Hypothesis,

2 volumes of nitric oxide give 1 volume of nitrogen and 1 volume of oxygen.

∴ 100 c.c. of nitric oxide give 50 c.c. of nitrogen and 50 c.c. of oxygen.

∴ total volume of residual mixture $= 50 + 50$
$= \underline{100 \text{ c.c.}}$

(vii) What volume of oxygen would be required to burn 20 c.c. of methane, CH_4?

$$CH_4 + 2O_2 = CO_2 + 2H_2O.$$

1 molecule of methane requires 2 molecules of oxygen.

∴ by Avogadro's Hypothesis,

1 volume of methane requires 2 volumes of oxygen.

∴ 20 c.c. of methane require 40 c.c. of oxygen.

<u>40 c.c. of oxygen.</u>

(viii) 50 c.c. of hydrogen were mixed with 100 c.c. of air, and the mixture was exploded. If air contains 21 per cent of oxygen by volume, what was the volume and composition of the residual gas?

$$2H_2 + O_2 = 2H_2O.$$

2 molecules of hydrogen require 1 molecule of oxygen, and

give steam, which, since the temperature is not stated to be above 100° C., we may presume condenses to liquid water.

By Avogadro's Hypothesis,

1 volume of oxygen requires 2 volumes of hydrogen.

∴ 21 c.c. of oxygen require 42 c.c. of hydrogen.

Hence there will be 50 − 42

= 8 c.c. of hydrogen left;

and there will also be left 100 − 21

= 79 c.c. of nitrogen.

∴ the residual gas is a mixture of 8 c.c. of hydrogen with 79 c.c. of nitrogen.

(ix) 7·5 c.c. of a hydrocarbon were mixed with 36 c.c. of oxygen and the mixture was exploded. The resulting gases occupied 28·5 c.c. On adding caustic soda solution, 15 c.c. of the gas were absorbed, and the remaining gas was completely absorbed by alkaline pyrogallol. Find the formula of the gas. [All measurements were taken at 15° C. 740 mm.]

Since the experiment was performed under conditions of temperature and pressure at which the steam produced would condense, the residual gases consisted of carbon dioxide and oxygen only. The volume of the carbon dioxide formed (diminution on adding caustic soda) was 15 c.c., and the volume of unused oxygen was 28·5 − 15 c.c. (diminution on adding alkaline pyrogallol). Hence volume of oxygen used = 36 − 13·5 = 22·5 c.c.

∴ 7·5 c.c. of the hydrocarbon required 22·5 c.c. oxygen and yielded 15 c.c. carbon dioxide,

∴ by Avogadro's Hypothesis,

1 molecule of the hydrocarbon required 3 molecules of oxygen and gave 2 molecules of carbon dioxide.

But each molecule of carbon dioxide, CO_2, contains 1 atom of carbon,

$\therefore$ the formula for the hydrocarbon is C_2H_y.

Carbon dioxide contains its own volume of oxygen, hence 1 molecule of the hydrocarbon requires 2 molecules of oxygen to convert its carbon into carbon dioxide. But 1 molecule of the hydrocarbon required 3 molecules of oxygen altogether; hence the third molecule of oxygen must have been used in converting the hydrogen of the hydrocarbon into water.

But one molecule of oxygen will combine with 2 molecules of hydrogen,

$$\therefore y = 4$$

and the formula is C_2H_4.

(x) The density of oxygen is 16; that of hydrogen is 1. How many c.c. of hydrogen will diffuse in the same time that 15 c.c. of oxygen diffuse (under the same conditions)?

$$\frac{R}{R'} = \frac{\sqrt{D'}}{\sqrt{D}}.$$

Let R be the rate of diffusion of hydrogen, and R′ that of oxygen; let D be the density of hydrogen, and D′ that of oxygen.

Then $$\frac{R}{R'} = \frac{\sqrt{16}}{\sqrt{1}} = \frac{4}{1} = 4.$$

Hence hydrogen diffuses four times as fast as oxygen, so that 60 c.c. of hydrogen will diffuse in the same time as 15 c.c. of oxygen.

60 c.c.

(xi) A gas is found to diffuse at two-thirds the rate

at which oxygen diffuses. If the density of oxygen is 16, what is the density of the gas?

$$\frac{R}{R'} = \frac{\sqrt{D'}}{\sqrt{D}}.$$

Let R = rate of diffusion of the gas and D = its density let R′ = rate of diffusion of oxygen and D′ its density.

Then

$$\frac{\frac{2}{3}}{1} = \frac{\sqrt{16}}{\sqrt{D}}$$

$$\therefore \frac{2}{3} = \frac{4}{\sqrt{D}}$$

$$\therefore \sqrt{D} = 6$$

$$\therefore D = 6 \times 6 = \underline{36}.$$

(xii) The rates of diffusion of carbon dioxide and ozone are approximately as 2·9 : 2·71. If the molecular weight of carbon dioxide is 44, what is the M.W. of ozone?

M.W. = 2 × vapour density.

∴ V.D. of carbon dioxide = 22.

$$\frac{R}{R'} = \frac{\sqrt{D'}}{\sqrt{D}}.$$

Let R = rate of diffusion of carbon dioxide and D = its vapour density; and let R′ = rate of diffusion of ozone and D′ its vapour density.

Then

$$\frac{2{\cdot}9}{2{\cdot}71} = \frac{\sqrt{D'}}{\sqrt{22}}$$

$$\therefore \frac{2{\cdot}9 \times 2{\cdot}9}{2{\cdot}71 \times 2{\cdot}71} = \frac{D'}{22}$$

$$\therefore D' = 25{\cdot}2.$$

∴ molecular weight of ozone $= 25{\cdot}2 \times 2$

$= 50{\cdot}4.$

PROBLEMS.

1. What is the weight of 22·4 litres of each of the following gases, at N.T.P.?

(i) Ammonia, NH_3;
(ii) Sulphur dioxide, SO_2;
(iii) Nitric oxide, NO;
(iv) Nitrous oxide, N_2O;
(v) Hydrogen chloride, HCl;
(vi) Carbon monoxide, CO;
(vii) Carbon dioxide, CO_2;
(viii) Chlorine, Cl_2;
(ix) Oxygen, O_2;
(x) Ozone, O_3.

2. What is the volume, at N.T.P., of:

(i) 8·5 gm. of ammonia, NH_3;
(ii) 71 gm. of chlorine, Cl_2;
(iii) 365 gm. of hydrogen chloride, HCl;
(iv) 9·6 gm. of ozone, O_3;
(v) 14 gm. of ethylene, C_2H_4;
(vi) 14 gm. of carbon monoxide, CO;
(vii) 13·2 gm. of carbon dioxide, CO_2;
(viii) 68 gm. of hydrogen sulphide, H_2S;
(ix) 27 gm. of hydrogen bromide, HBr;
(x) 40 gm. of helium, He?

3. What volume of nitrogen, at N.T.P., could be obtained from 100 c.c. of the following gases:

(i) Ammonia, NH_3;
(ii) Nitric oxide, NO;
(iii) Nitrous oxide, N_2O;
(iv) Methylamine, CH_5N;
(v) Nitrosyl fluoride, NOF?

4. What volume of hydrogen, at N.T.P., could be obtained from 100 c.c. of the following gases:

(i) Methane, CH_4;
(ii) Ethane, C_2H_6;
(iii) Propane, C_3H_8;
(iv) Acetylene, C_2H_2;
(v) Phosphine, PH_3;
(vi) Hydrogen iodide, HI;
(vii) Ethyl chloride, C_2H_5Cl;
(viii) Methyl chloride, CH_3Cl;
(ix) Formaldehyde, CH_2O;
(x) Methylamine, CH_5N?

5. Find the weight, at N.T.P., of:

(i) 112 litres of oxygen, O_2;
(ii) 6·72 litres of chlorine, Cl_2;
(iii) 5·6 litres of nitrogen, N_2;
(iv) 16·8 litres of ammonia, NH_3;
(v) 3·36 litres of carbon dioxide, CO_2;
(vi) 224 c.c. of carbon monoxide, CO;
(vii) 1·12 c.c. of krypton, Kr;
(viii) 2240 litres of hydrogen chloride, HCl;
(ix) *22·4 litres of fluorine, F_2;*
(x) 156·8 litres of hydrogen sulphide, H_2S.

6. 10 gm. of a certain gas at N.T.P. occupied 4·44 litres. What is its molecular weight?

7. 26 gm. of gas were found to occupy the same volume as 9 gm. of ammonia under the same conditions of temperature and pressure. What is the G.M.W. of the gas?

8. Three litres of ammonia were partially decomposed into nitrogen and hydrogen by continued sparking. If 98 per cent of the ammonia was thus split up,

calculate the volume and composition of the remaining gas. [All measurements made at the same temperature and pressure.]

9. 100 c.c. of a mixture of nitrogen and oxygen were mixed with excess of hydrogen and the mixture was exploded. A diminution in volume of 63 c.c. occurred. What was the composition of the mixture? [All measurements at 15° C. 760 mm.]

10. A mixture of nitrogen and hydrogen, occupying 50 c.c., was mixed with 50 c.c. of oxygen and the mixture was exploded. The residual gases occupied 40 c.c., of which 30 c.c. were absorbed by alkaline pyrogallol. Calculate the percentage by volume of hydrogen in the original mixture. [All measurements at 15° C. 755 mm.]

11. 100 c.c. of air were mixed with 60 c.c. of hydrogen and the mixture was exploded. Calculate the volume and composition of the residual gas: (*a*) if the whole experiment were conducted at room temperature and pressure, and (*b*) if it were conducted at such a temperature and pressure that the steam formed did not condense.

12. A mixture of ozone and oxygen occupies 50 c.c. On heating, to convert the ozone into oxygen, and bringing the gas to the original temperature and pressure, the volume increased to 51 c.c. What was the percentage by volume of ozone in the mixture?

13. 10 c.c. of a mixture of methane, CH_4, and nitrogen was sparked with excess of oxygen. The

volume of carbon dioxide formed was 8·5 c.c. Find the composition of the mixture by volume.

14. 25 c.c. of a mixture of carbon monoxide and carbon dioxide diminished in volume by 10 c.c. on shaking with caustic potash solution. Find the percentage composition of the mixture by volume.

15. 15 c.c. of a gaseous hydrocarbon required for complete combustion 45 c.c. of oxygen, and yielded 30 c.c. of carbon dioxide. Calculate the formula of the hydrocarbon.

16. 12 c.c. of a gaseous hydrocarbon required for complete combustion 60 c.c. of oxygen, and yielded 36 c.c. of carbon dioxide. Calculate the formula of the hydrocarbon.

17. 10 c.c. of a gaseous hydrocarbon were exploded with 40 c.c. of oxygen. The residual gases occupied 35 c.c., and this volume diminshed to 15 c.c. on addition of caustic soda solution. Assuming that all measurements were made at 15° C. 750 mm., calculate the formula of the hydrocarbon.

18. Find the composition of a *mixture* of carbon monoxide, hydrogen, and nitrogen from the following data: 32 c.c. of the mixture, on explosion with excess of oxygen, gave 33 c.c. of residual gas. Of the latter, 12 c.c. were absorbed by potash and a further 13 c.c. by alkaline pyrogallol. All measurements were made at room temperature and pressure.

19. A gas is found to diffuse at three-quarters of the rate at which oxygen diffuses. If the vapour density of oxygen is 16, what is the M.W. of the gas?

20. How many c.c. of helium will diffuse in the same time that 10 c.c. of hydrogen bromide diffuse, under the same conditions?

21. The rates of diffusion of oxygen and methyl chloride are approximately in the ratio of 5 : 4. If the molecular weight of oxygen is 32, what is the approximate molecular weight of methyl chloride?

CHAPTER IX

VOLUMETRIC ANALYSIS

1. A **standard** solution is a solution whose concentration is known.

2. A normal solution is a solution 1 litre (1000 c.c.) of which contains the gram-equivalent of the dissolved substance. It is usually written as $N\ H_2SO_4$, N caustic soda, etc.

Decinormal, semi-normal, twice normal, etc., solutions ($N/10$, $N/2$, $2N$) are respectively one-tenth, one-half, and twice, etc., the concentration of normal solutions.

3. Equal volumes of solutions of the same normality will *exactly* react with one another.

EXAMPLES.

(*a*) 36·7 c.c. of N HCl require 36·7 c.c. N NaOH, 36·7 c.c. N KOH, 36·7 c.c. $N\ Na_2CO_3$, etc.

(*b*) 27·8 c.c. of $N\ H_2SO_4$ will neutralize just the same volume of a solution of an alkali as will 27·8 c.c. N HCl or 27·8 c.c. of any other normal acid solution.

4. *Strengths of common normal solutions*:

Substance	*Gm. per Litre in Normal Solution*
Sulphuric acid, H_2SO_4	49
Hydrochloric acid, HCl	36·5
Nitric acid, HNO_3	63
Potassium hydroxide, KOH	56
Sodium hydroxide, NaOH	40
Sodium carbonate anhydrous, Na_2CO_3	53
Washing soda (sodium carbonate decahydrate), $Na_2CO_3.10H_2O$	143
Oxalic acid crystals (dihydrate), $H_2C_2O_4.2H_2O$	63
Oxalic acid anhydrous, $H_2C_2O_4$	45

5. Titrations between the above acids and KOH or NaOH:

Use *litmus* as indicator.

Titrations between the above acids and Na_2CO_3:

Use *litmus* as indicator and boil solution to remove carbonic acid as carbon dioxide, or

Use *methyl orange* as indicator (unaffected by carbonic acid, H_2CO_3).

6. The basicity of an acid is the number of hydrogen atoms, replaceable by a metal, contained in one molecule of the acid. The *molecular weight* of an acid is thus numerically equal to the *equivalent* × *basicity*.

EXAMPLES.

(*a*) 2·12 gm. of a solid acid were dissolved in distilled water and made up to 250 c.c. It was found that 14·8 c.c. of the acid solution were required to neutralize 20 c.c. of decinormal sodium hydroxide solution. Calculate the normality of the acid solution and the

equivalent of the acid. If the basicity of the acid is 2, what is its molecular weight?

If the acid solution had been $N/10$, the volume of it required to neutralize 20 c.c. of $N/10$ sodium hydroxide would have been 20 c.c. But only 14·8 c.c. were required,

$\therefore$ strength of acid solution is $\frac{20}{14 \cdot 8} \times N/10$,

i.e. 1·35 times decinormal.

If 2·12 gm. in 250 c.c. (i.e. 8·48 gm. per litre) is $\frac{20}{14 \cdot 8} \times N/10$,

then $N/10$ is $\frac{8 \cdot 48 \times 14 \cdot 8 \text{ gm.}}{20}$ per litre

$= 6 \cdot 28$ gm. per litre.

But a decinormal solution of the acid contains one-tenth of the gram equivalent per litre;

$\therefore$ gram equivalent $= 10 \times 6 \cdot 28$
$= 62 \cdot 8$ gm.

$\therefore$ equivalent $= \underline{62 \cdot 8}$.

Also, M.W. = equivalent × basicity.
But the basicity is stated to be 2.

$\therefore$ M.W. $= \underline{125 \cdot 6}$.

(*b*) 25 c.c. of a solution of ammonium chloride were boiled with 50 c.c. N caustic potash till all the ammonia was driven off. The residual caustic potash required 23·6 c.c. N sulphuric acid to neutralize it. Calculate the strength of the ammonium chloride solution in gm. per litre. [N = 14; H = 1; Cl = 35·5; K = 39; O = 16.]

Equation:

$$\underset{53 \cdot 5}{NH_4Cl} + \underset{56}{KOH} = KCl + NH_3 + H_2O$$

$\therefore$ 1 litre of N KOH ≡ 53·5 gm. NH_4Cl
(56 gm. per litre)

1 c.c. N H_2SO_4 ≡ 1 c.c. N KOH

$\therefore$ 23·6 c.c. N H_2SO_4 ≡ 23·6 c.c. N KOH

$\therefore$ volume of N KOH used = 26·4 c.c.

But $\quad 1000$ c.c. N KOH $= 53{\cdot}5$ gm. NH_4Cl

$\therefore \quad 26{\cdot}4$ c.c. N KOH $= \frac{53{\cdot}5 \times 26{\cdot}4}{1000}$ gm. NH_4Cl.

This is the weight of ammonium chloride in 25 c.c. of the ammonium chloride solution.

$\therefore$ strength of this solution in gm. per litre

$$= \frac{53{\cdot}5 \times 26{\cdot}4}{1000} \times \frac{1000}{25}$$

$$= 56{\cdot}5 \text{ gm.}$$

The strength of the ammonium chloride solution is 56·5 gm. per litre.

[In terms of normality, this would be $\frac{56{\cdot}5}{53{\cdot}5} N$.]

(*c*) What volume of normal hydrochloric acid would be required to liberate 250 c.c. carbon dioxide (measured at N.T.P.) from sodium bicarbonate? What weight of sodium bicarbonate would be needed? [Na = 23, H = 1; C = 12; O = 16; Cl = 35·5.]

Equation:

$$\underset{36{\cdot}5}{HCl} + \underset{84}{NaHCO_3} = NaCl + H_2O + \underset{22{\cdot}4 \text{ litres at N.T.P.}}{CO_2}$$

If 22·4 litres CO_2 are yielded by 84 gm. sodium bicarbonate, 250 c.c. CO_2 are yielded by $\frac{84 \times 250}{22{,}400}$

$= \underline{0{\cdot}94 \text{ gm. sodium bicarbonate.}}$

Also, 1 litre of N HCl liberates 22·4 litres CO_2 at N.T.P.

If 22·4 litres CO_2 are liberated by 1 litre N HCl, then 250 c.c. CO_2 are liberated by $\frac{1000 \times 250}{22{,}400}$ c.c. N HCl

$= \underline{11{\cdot}2 \text{ c.c. } N \text{ hydrochloric acid.}}$

PROBLEMS.

1. Express the strengths of normal solutions of the following substances in grams per litre:

(*a*) Sulphuric acid, H_2SO_4;

(*b*) Hydrochloric acid, HCl;

(c) Nitric acid, HNO_3;
(d) Sodium hydroxide, NaOH;
(e) Potassium hydroxide, KOH;
(f) Sodium carbonate, Na_2CO_3 (anhydrous);
(g) Sodium carbonate decahydrate, $Na_2CO_3.10H_2O$ (washing-soda);
(h) Oxalic acid, $H_2C_2O_4$ (anhydrous);
(i) Oxalic acid dihydrate, $H_2C_2O_4.2H_2O$ (oxalic acid crystals).

2. Express the strengths of the following solutions in terms of normality:

(a) Sulphuric acid, 4·9 gm. H_2SO_4 per litre;
(b) Hydrochloric acid, 73 gm. HCl per litre;
(c) Nitric acid, 63 gm. per litre;
(d) Nitric acid, 12·6 gm. per litre;
(e) Sodium hydroxide, 5·0 gm. per litre;
(f) Caustic potash, 112 gm. per litre;
(g) Sodium carbonate, 10·6 gm. anhydrous salt per litre;
(h) Oxalic acid, 50 gm. anhydrous acid per litre;
(i) Oxalic acid, 50 gm. crystalline dihydrate per litre.

3. The molecular weight of an acid is 120 and its basicity is 2. What is the strength of a decinormal solution of it, in grams per litre?

4. A decinormal solution of a tribasic acid contains 7·5 gm. of the acid per litre. What is the molecular weight of the acid?

5. How many c.c. of $N/10$ sodium hydroxide are required to neutralize 10 c.c. of (a) decinormal camphor-sulphuric acid (b) 10 c.c. of N oxalic acid, (c) $N/5$ hydrochloric acid, (d) $2N$ sulphuric acid, (e) seminormal nitric acid?

6. The equivalent of ammonia is 17. 28 c.c. of $N/10$ hydrochloric acid were required to neutralize

25 c.c. of a solution of ammonia. Calculate the strength of the ammonia solution in terms of normality, and in grams of ammonia per litre.

7. The formula of sodium bisulphate is $NaHSO_4$, and the substance behaves as a monobasic acid. How many grams of it would be required to neutralize the same volume of normal potassium hydroxide solution as is neutralized by 150 c.c. of nitric acid containing 63 gm. HNO_3 per litre?

8. Some lime-water contains 1·0 gm. of calcium hydroxide per litre. 50 c.c. of it are found to neutralize 35 c.c. of a solution of hydrochloric acid. Calculate the strength of the hydrochloric acid in terms of normality. The formula for calcium hydroxide is $Ca(OH)_2$, and its equivalent is half its molecular weight.

9. A laboratory assistant was told to make up a decinormal solution of caustic soda, but when the solution was tested by titration against $N/10$ acid, it was found that 20 c.c. of the alkali required 20·4 c.c. of the acid. If the assistant has 10 litres of the caustic soda solution left, how much distilled water must he add to it to make it exactly decinormal?

10. 25 c.c. of caustic soda solution, containing 50 gm. NaOH per litre, neutralized 31·3 c.c. of a solution of nitric acid containing 6·3 gm. HNO_3 per litre. How many grams of nitric acid will neutralize 1·0 gm. of caustic soda?

11. A specimen of anhydrous sodium carbonate was accidentally allowed to get rather damp. 6 gm. of the damp specimen was dissolved in water and made up to

1 litre. 25 c.c. of this solution required 27·5 c.c. of $N/10$ acid for neutralization. Calculate the percentage by weight of water in the damp specimen.

12. 0·25 gm. of potassium bicarbonate neutralizes 15·0 c.c. of $N/6$ hydrochloric acid. What is the equivalent of potassium bicarbonate?

13. 1·0 gm. of Iceland spar (calcium carbonate) was dissolved in 50 c.c. of normal nitric acid. To neutralize the excess of acid, 30 c.c. of normal alkali were required. What is the equivaleut of Iceland spar?

14. 2·5 gm. of a mixture of magnesium oxide and sand was added to 200 c.c. of normal hydrochloric acid. It was found that 27·5 c.c. of normal sodium hydroxide were required to neutralize a quarter of the resulting liquid. What percentage by weight of magnesium oxide did the mixture contain?

15. 0·088 gm. magnesium was dissolved in 100 c.c. of decinormal sulphuric acid. To neutralize the excess of acid, 13·8 c.c. of $N/5$ alkali were required. Calculate the equivalent of magnesium.

16. Calculate the percentage composition by weight of a mixture of sodium chloride and ammonium chloride from the following data: 1·50 gm. of the mixture was boiled with 50 c.c. of normal caustic potash until all the ammonia was driven off. To neutralize the unused alkali, 24·6 c.c. of normal acid were required.

17. 0·75 gm. of a salt known to be either ammonium chloride or ammonium sulphate was boiled with 30 c.c. of normal caustic soda until all the ammonia was

25 c.c. of a solution of ammonia. Calculate the strength of the ammonia solution in terms of normality, and in grams of ammonia per litre.

7. The formula of sodium bisulphate is $NaHSO_4$, and the substance behaves as a monobasic acid. How many grams of it would be required to neutralize the same volume of normal potassium hydroxide solution as is neutralized by 150 c.c. of nitric acid containing 63 gm. HNO_3 per litre?

8. Some lime-water contains 1·0 gm. of calcium hydroxide per litre. 50 c.c. of it are found to neutralize 35 c.c. of a solution of hydrochloric acid. Calculate the strength of the hydrochloric acid in terms of normality. The formula for calcium hydroxide is $Ca(OH)_2$, and its equivalent is half its molecular weight.

9. A laboratory assistant was told to make up a decinormal solution of caustic soda, but when the solution was tested by titration against $N/10$ acid, it was found that 20 c.c. of the alkali required 20·4 c.c. of the acid. If the assistant has 10 litres of the caustic soda solution left, how much distilled water must he add to it to make it exactly decinormal?

10. 25 c.c. of caustic soda solution, containing 50 gm. NaOH per litre, neutralized 31·3 c.c. of a solution of nitric acid containing 6·3 gm. HNO_3 per litre. How many grams of nitric acid will neutralize 1·0 gm. of caustic soda?

11. A specimen of anhydrous sodium carbonate was accidentally allowed to get rather damp. 6 gm. of the damp specimen was dissolved in water and made up to

0·56 gm. of the compound was treated in this way and the ammonia was collected in 50 c.c. of $N/5$ sulphuric acid. To neutralize the excess of acid, 6·2 c.c. of $N/5$ alkali were required. What is the percentage by weight of nitrogen in the compound?

24. To neutralize a solution made by dissolving 2·00 gm. of a mixture of anhydrous sodium carbonate and anhydrous potassium carbonate in water, 33·4 c.c. of normal nitric acid were required. How much sodium carbonate was there in the 2·00 gm. of the mixture?

driven off. To neutralize the excess of alkali, 18·6 c.c. of normal nitric acid were used. Which is the salt: the chloride or the sulphate? How much alkali would 0·75 gm. of the other salt have required?

18. To neutralize 10 gm. of a saturated solution of sodium carbonate decahydrate, $Na_2CO_3.10H_2O$, at 20° C., 15·05 c.c. of *N*-hydrochloric acid were required. What is the solubility of sodium carbonate decahydrate at this temperature?

19. 0·93 gm. of a hydrated form of sodium carbonate, $Na_2CO_3.xH_2O$, required 15·0 c.c. of normal acid for neutralization. Calculate the value of *x*.

20. What weight of oxalic acid crystals, $H_2C_2O_4.2H_2O$, would be required to make 50 c.c. of a normal solution of the acid? How much water should be added to convert the 50 c.c. of normal acid into a decinormal solution?

21. It is desired to make up an accurately decinormal solution of sodium carbonate, Na_2CO_3, from a specimen of the anhydrous substance contaminated with 8 per cent of common salt, NaCl. How much of the substance should be weighed out in order to make 250 c.c. of the required solution?

22. 6·0 gm. of an acid were dissolved in water and made up to 200 c.c. To neutralize 25 c.c. of caustic soda solution, containing 4 gm. NaOH per litre, 11·3 c.c. of the acid solution were required. What is the equivalent of the acid?

23. In the analysis of a certain compound containing nitrogen, the latter was converted into ammonia.

0·56 gm. of the compound was treated in this way and the ammonia was collected in 50 c.c. of $N/5$ sulphuric acid. To neutralize the excess of acid, 6·2 c.c. of $N/5$ alkali were required. What is the percentage by weight of nitrogen in the compound?

24. To neutralize a solution made by dissolving 2·00 gm. of a mixture of anhydrous sodium carbonate and anhydrous potassium carbonate in water, 33·4 c.c. of normal nitric acid were required. How much sodium carbonate was there in the 2·00 gm. of the mixture?

driven off. To neutralize the excess of alkali, 18·6 c.c. of normal nitric acid were used. Which is the salt: the chloride or the sulphate? How much alkali would 0·75 gm. of the other salt have required?

18. To neutralize 10 gm. of a saturated solution of sodium carbonate decahydrate, $Na_2CO_3.10H_2O$, at 20° C., 15·05 c.c. of *N*-hydrochloric acid were required. What is the solubility of sodium carbonate decahydrate at this temperature?

19. 0·93 gm. of a hydrated form of sodium carbonate, $Na_2CO_3.xH_2O$, required 15·0 c.c. of normal acid for neutralization. Calculate the value of x.

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23. In the analysis of a certain compound containing nitrogen, the latter was converted into ammonia.

of 120° C. throughout. What will be the volume of the residual mixture of gases, assuming that air contains 21 per cent of oxygen and 79 per cent of nitrogen, by volume? (L.M.)

Gay-Lussac's Law, p. 71.

Since the temperature is 120° C., the steam formed will remain as steam.

$$\text{Volume of oxygen in 30 c.c. of air} = \frac{21 \times 30}{100} \text{ c.c.}$$
$$= 6{\cdot}3 \text{ c.c.}$$

This will combine with 12·6 c.c. of hydrogen to give 12·6 c.c. of steam (deduction from the equation $2H_2 + O_2 = 2H_2O$, by Avogadro's Hypothesis).

Hence residual gases are:

(a) 12·6 c.c. steam;

(b) 60 − 12·6 = 47·4 c.c. hydrogen;

(c) 30 − 6·3 = 23·7 c.c. nitrogen.

∴ total volume of residual mixture = 83·7 c.c.

[Shorter method: Since the steam formed will occupy the same volume as the hydrogen used, the only change in volume will be due to the disappearance of the oxygen in 30 c.c. air. This is $\frac{21 \times 30}{100} = 6{\cdot}3$ c.c.

Original volume = 90 c.c.

∴ final volume = 90 − 6·3 = 83·7 c.c.]

3. An element E forms two gaseous oxides containing respectively 36·3 and 53·3 per cent of oxygen. One gram of these oxides occupies 505 c.c. and 735 c.c. respectively, the volume being measured at standard temperature and pressure. Calculate the equivalent weights of E and its probable atomic weight, and assign formulae to the oxides. (L.M.)

CHAPTER X

MISCELLANEOUS PROBLEMS: WORKED EXAMPLES

1. Define the term *equivalent*. 0·426 gm. of silver were dissolved in nitric acid and the silver then precipitated in the form of silver chloride by addition of excess of hydrochloric acid. The weight of the silver chloride was 0·566 gm. What is the equivalent of silver, from these figures? (L.M.)

Definition of equivalent in Chap. II. Silver chloride is a compound of silver and chlorine.

The equivalent of chlorine is 35·5, hence equivalent of silver will be the number of grams of silver that will combine with 35·5 gm. of chlorine.

$$\begin{aligned} \text{Weight of silver chloride} &= 0{\cdot}566 \text{ gm.} \\ \text{Weight of silver} &= \underline{0{\cdot}426 \text{ gm.}} \\ \therefore \text{weight of chlorine} &= \underline{0{\cdot}140 \text{ gm.}} \end{aligned}$$

If 0·140 gm. chlorine combines with 0·426 gm. silver,

$$\text{then } 35{\cdot}5 \text{ gm. chlorine combine with } \frac{0{\cdot}426 \times 35{\cdot}5}{0{\cdot}140}$$

$$= 108{\cdot}0 \text{ gm. silver.}$$

$$\therefore \underline{\text{equivalent of silver} = 108{\cdot}0.}$$

2. State and illustrate Gay-Lussac's Law of the Combination of Gases by Volume.

A mixture of 30 c.c. of air and 60 c.c. of hydrogen is sparked in an apparatus maintained at a temperature

of 120° C. throughout. What will be the volume of the residual mixture of gases, assuming that air contains 21 per cent of oxygen and 79 per cent of nitrogen, by volume? (L.M.)

Gay-Lussac's Law, p. 71.

Since the temperature is 120° C., the steam formed will remain as steam.

$$\text{Volume of oxygen in 30 c.c. of air} = \frac{21 \times 30}{100} \text{ c.c.}$$
$$= 6{\cdot}3 \text{ c.c.}$$

This will combine with 12·6 c.c. of hydrogen to give 12·6 c.c. of steam (deduction from the equation $2H_2 + O_2 = 2H_2O$, by Avogadro's Hypothesis).

Hence residual gases are:

(a) 12·6 c.c. steam;

(b) 60 − 12·6 = 47·4 c.c. hydrogen;

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∴ total volume of residual mixture = 83·7 c.c.

[Shorter method: Since the steam formed will occupy the same volume as the hydrogen used, the only change in volume will be due to the disappearance of the oxygen in 30 c.c. air.

This is $\frac{21 \times 30}{100} = 6{\cdot}3$ c.c.

Original volume = 90 c.c.

∴ final volume = 90 − 6·3 = 83·7 c.c.]

3. An element E forms two gaseous oxides containing respectively 36·3 and 53·3 per cent of oxygen. One gram of these oxides occupies 505 c.c. and 735 c.c. respectively, the volume being measured at standard temperature and pressure. Calculate the equivalent weights of E and its probable atomic weight, and assign formulae to the oxides. (L.M.).

The equivalent of oxygen is 8,

$\therefore$ in first oxide,

since 26·3 gm. oxygen combine with 63·7 gm. E

$$8 \quad ,, \quad ,, \quad ,, \quad ,, \quad \frac{63 \cdot 7 \times 8}{36 \cdot 3}$$

$$= \underline{14 \cdot 0 \text{ gm. E}},$$

and this is the equivalent of E in the first oxide.

Similarly in the second oxide,

53·3 gm. oxygen combine with 46·7 gm. E,

$$\therefore \quad 8 \quad ,, \quad ,, \quad ,, \quad ,, \quad \frac{46 \cdot 7 \times 8}{53 \cdot 3}$$

$$= \underline{7 \cdot 0 \text{ gm. E}},$$

and this is the equivalent of E in the second oxide.

$\therefore$ A.W. of *element* $= 7 \times n$, where n is a small whole number.

505 c.c. of the first oxide weighed 1 gm. at N.T.P.

$\therefore$ 22,400 c.c. of the first oxide weighed 44·4 gm. at N.T.P.

$\therefore$ M.W. of first oxide $= 44 \cdot 4.$

Similarly, M.W. of second oxide $= \dfrac{22{,}400 \times 1}{735}$

$= 30 \cdot 5.$

If the A.W. of the element were 7, the formula of the first oxide must be E_4O, since this is the only formula that will correspond to the M.W. ($4 \times 7 + 16 = 44$). But this would make the valency of the element 0·5 and is therefore presumably wrong. Hence the atomic weight is not 7. Suppose it to be 14. Then the formula for the first oxide will be E_2O ($2 \times 14 + 16 = 44$), and that of the second oxide EO ($14 + 16 = 30$).

An atomic weight of 21 will not fit the figures for the M.W. of the oxides, $\therefore$ the atomic weight of the element must be 14 and the formulae of its oxides E_2O and EO.

4. Describe the preparation and properties of *one* of the oxides of nitrogen.

50 c.c. of a gaseous compound of nitrogen and oxygen when exploded with an equal volume of

hydrogen yielded 50 c.c. of nitrogen. What is the composition (by volume) of the compound? (L.M.)

See *A Junior Chemistry*, pp. 167-70.

If 50 c.c. of the compound yielded 50 c.c. of nitrogen, then by Avogadro's Hypothesis:

1 molecule of the compound contains 1 molecule of nitrogen, and the formula is therefore N_2O_x.

But the volume of hydrogen required was equal to that of the compound, i.e.:

1 molecule of the compound requires 1 molecule of hydrogen. The hydrogen combines with the oxygen in the compound. But 1 molecule of hydrogen, H_2, combines with half a molecule [i.e. 1 atom] of oxygen:

$$H_2 + \tfrac{1}{2}O_2 = H_2O.$$

Therefore, 1 molecule of the compound contains 1 atom of oxygen;

$\therefore x = 1$ and the formula is N_2O.

The composition by volume of this compound (Avogadro's Hypothesis) is:

Nitrogen : Oxygen as 2 : 1.

5. On analysis, a compound was found to have the following percentage composition by weight: carbon 52·2; hydrogen 13·0; oxygen 34·8. Its vapour density was found, by Victor Meyer's method, to be 23. What is its formula? (B.)

See p. 45.

$$\textit{Carbon} \quad \frac{52\cdot2}{12} = 4\cdot35$$

$$\textit{Hydrogen} \quad \frac{13\cdot0}{1} = 13\cdot0$$

$$\textit{Oxygen} \quad \frac{34\cdot8}{16} = 2\cdot18$$

$$\therefore C : H : O = 4\cdot35 : 13\cdot0 : 2\cdot18$$
$$= 2 : 6 : 1,$$

$\therefore$ Empirical formula $= C_2H_6O$.

But V.D. = 23. $\therefore$ M.W. = 46.

But M.W. of $C_2H_6O = 2 \times 12 + 6 + 16$
$= 46.$

$\therefore$ true formula also is C_2H_6O.

6. What is the nature and amount of the precipitate produced by passing pure carbon dioxide into 500 c.c. of lime-water containing 1·0 gm. of calcium hydrate per litre? (O. and C.)

'Calcium hydrate' is a name sometimes (incorrectly) used for calcium hydroxide, $Ca(OH)_2$.

The equation for the action is:

$$\underset{74}{Ca(OH)_2} + CO_2 = \underset{100}{CaCO_3} \downarrow + H_2O.$$

The precipitate is calcium carbonate. 500 c.c. of the lime-water will contain $\frac{500}{1000} \times 1·0 = 0·5$ gm. of calcium hydroxide.

74 gm. of calcium hydroxide yield 100 gm. of carbonate

$\therefore$ 0·5 gm. „ „ „ „ $\frac{100 \times 0·5}{74}$

$= 0·68$ gm.

Hence the *nature* of the precipitate is calcium carbonate, and the *weight* of the precipitate is 0·68 gm.

7. One gram of a metal was converted into 2·90 gm. of chloride by burning it in chlorine. Calculate the equivalent of the metal. What further data would be required to fix the atomic weight of the metal? (O. and C.)

The weight of chlorine in 2·90 gm. of the chloride is:

$2·90 - 1 = 1·90$ gm.

The equivalent of chlorine is 35·5.

Since 1·90 gm. of chlorine combine with 1 gm. of metal,

35·5 gm. „ „ „ „ $\frac{1 \times 35·5}{1·90}$

$= 18·7$ gm. of metal.

$\therefore$ equivalent of metal $= 18·7$.

To fix the atomic weight of the metal, the valency must also be known, since

equivalent $\times$ *valency* $=$ *atomic weight*

A rough value for the atomic weight could be found from Dulong and Petit's Law:

Atomic weight of solid element × *specific heat* = *about* 6·4, and this rough atomic weight divided by the equivalent would give the approximate valency. But the valency must be a whole number; hence the nearest whole number to the approximate valency is taken as the true valency, and this multiplied by the equivalent gives the atomic weight.

8. What do you understand by the equivalent of a base and of an acid?

30 c.c. of a solution containing 1·825 gm. of hydrogen chloride per litre were found to neutralize exactly 40 c.c. of a solution containing 1·99 gm. of a base per litre. Calculate the equivalent of the base.

(O. and C.)

See *A Junior Chemistry*, p. 367.

The gram equivalent (36·5 gm.) of hydrochloric acid will neutralize the gram equivalent of a base.

$$\frac{30 \times 1{\cdot}825}{1000} \text{ gm. of the acid} = \frac{40 \times 1{\cdot}99}{1000} \text{ gm. of the base,}$$

$$\therefore 36{\cdot}5 \text{ gm. of the acid} = \frac{40 \times 1{\cdot}99 \times 1000 \times 36{\cdot}5}{1000 \times 30 \times 1{\cdot}825}$$

$$= 53{\cdot}1 \text{ gm. of the base.}$$

$\therefore$ the equivalent of the base is 53·1.

9. Write an equation to show the chemical reaction that takes place when carbon dioxide is passed over red-hot carbon. Describe the properties of the resulting gas. What will be the final volume when 10 c.c. of this gas are mixed with 30 c.c. of air and the mixture sparked? (O. and C.)

See *A Junior Chemistry*, p. 206.

The gas is carbon monoxide. When this is exploded with air, carbon dioxide is formed:

$$2CO + O_2 = 2CO_2.$$

2 molecules of carbon monoxide require 1 molecule of oxygen and give 2 molecules of carbon dioxide.

∴ by Avogadro's Hypothesis,

2 vol. of carbon monoxide require 1 vol. of oxygen and give 2 vol. of carbon dioxide,

∴ 10 c.c. of carbon monoxide require 5 c.c. of oxygen and give 10 c.c. of carbon dioxide.

Air contains 21 per cent of oxygen by volume, hence 30 c.c. contain 6·3 c.c.; so there is more than enough oxygen present to burn all the carbon monoxide.

Hence, from the 40 c.c. of original mixture, 10 c.c. of carbon monoxide and 5 c.c. of oxygen will vanish, but 10 c.c. of *carbon dioxide will be formed.*

$$\therefore \text{ final volume} = 40 - (10 + 5) + 10$$
$$= \underline{35 \text{ c.c.}}$$

10. (*a*) What volume of hydrogen at 15° C. and 745 mm. pressure can be obtained by the action of acid on 1 gm. of zinc?

(*b*) Calculate the equivalent of a metal whose weight is increased by 25 per cent when it is heated to constant weight in oxygen. (O. and C.)

(*a*) Zinc is bivalent, so whatever acid is used, one atom of zinc will always liberate one molecule of hydrogen:

$$Zn + \text{acid} = \text{Zinc salt} + H_2.$$

∴ 65 gm. of zinc liberate 22·4 litres of hydrogen at N.T.P.

∴ 1 gm. ,, ,, liberates $\frac{22 \cdot 4}{65}$,, ,, ,, ,, ,,

At 15° C. and 745 mm. pressure this volume will become

$$\frac{22 \cdot 4 \times 288 \times 760 \times 1000}{65 \times 273 \times 745} \text{ c.c.}$$
$$= \underline{371 \text{ c.c.}}$$

(b) If the weight is increased by 25 per cent on formation of the oxide, then

25 gm. of oxygen combine with 100 gm. of metal,

$$\therefore 8 \text{ gm. } ,, \quad ,, \quad ,, \quad ,, \quad \frac{100 \times 8}{25} \quad ,, \quad ,, \quad ,,$$

$$= 32 \text{ gm.}$$

$\therefore$ equivalent of metal = 32.

11. What volume of oxygen is required to burn completely 50 c.c. of hydrogen sulphide and what will be the volume of the resulting gases? (All the volumes are to be considered at a constant temperature (120° C.) and a constant pressure.) (B.)

The equation is:

$$2H_2S + 3O_2 = 2H_2O + 2SO_2.$$

Since the temperature is above 100° C., the water will remain in the gaseous state as steam.

2 molecules of hydrogen sulphide require 3 molecules of oxygen and yield 2 molecules of steam and 2 molecules of sulphur dioxide;

$\therefore$ by Avogadro's Hypothesis,

2 vols. of hydrogen sulphide require 3 vols. of oxygen and yield 2 vols. of steam and 2 vols. of sulphur dioxide.

$\therefore$ 50 c.c. of hydrogen sulphide require 75 c.c. of oxygen, and yield 100 c.c. of mixed steam and sulphur dioxide.

12. A solid substance contained 14·3 per cent carbon, 1·2 per cent hydrogen, 57·1 per cent oxygen, and 27·4 per cent sodium. On heating this, a gas was evolved which contained 27·3 per cent carbon, and 72·7 per cent oxygen by weight. Calculate the formula of each substance and construct an equation in words and in symbols to represent the chemical

change. How would you identify each of the three products of the reaction? (B.)

$$\textit{Carbon} \quad \frac{14\cdot3}{12} = 1\cdot2$$

$$\textit{Hydrogen} \quad \frac{1\cdot2}{1} = 1\cdot2$$

$$\textit{Oxygen} \quad \frac{57\cdot1}{16} = 3\cdot6$$

$$\textit{Sodium} \quad \frac{27\cdot4}{23} = 1\cdot2$$

$$\therefore \text{Na} : \text{H} : \text{C} : \text{O} = 1\cdot2 : 1\cdot2 : 1\cdot2 : 3\cdot6$$
$$= 1 : 1 : 1 : 3$$

$\therefore$ empirical formula $= NaHCO_3$.

As no further data are given, we may take this to be the true formula for purposes of making the equation.

Formula of gas:

$$\textit{Carbon} \quad \frac{27\cdot3}{12} = 2\cdot3$$

$$\textit{Oxygen} \quad \frac{72\cdot7}{16} = 4\cdot6$$

$\therefore$ empirical formula $= CO_2$.

Equation:

$$2NaHCO_3 = Na_2CO_3 + H_2O + CO_2.$$

In words:

2 molecules of sodium bicarbonate, on heating, yield 1 molecule of sodium carbonate, 1 molecule of steam, and 1 molecule of carbon dioxide.

Identification:

(*a*) Sodium carbonate.
- (i) Na — yellow flame.
- (ii) CO_3 (carbonate radical) — effervescence in cold with dilute acid, carbon dioxide being evolved.

(*b*) Water.
Anhydrous copper sulphate turned from white to blue.

(*c*) Carbon dioxide.
Lime-water turned milky.

13. 70 c.c. of hydrogen and 30 c.c. of oxygen (both measured at N.T.P.) are mixed together and heated to 100° C. The mixture is then sparked. What will be the total volume after sparking?

(B.)

70 c.c. of hydrogen at N.T.P. will become

$$\frac{70 \times 373}{273} = 95{\cdot}6 \text{ c.c. at } 100^\circ \text{ C. } 760 \text{ mm.}$$

Similarly 30 c.c. of oxygen at N.T.P. will become

$$\frac{30 \times 373}{273} = 41{\cdot}0 \text{ c.c. at } 100^\circ \text{ C. } 760 \text{ mm.}$$

The equation is:

$$2H_2 + O_2 = 2H_2O,$$

and since the temperature is 100° C. the water will be in the form of steam.

2 molecules of hydrogen require 1 molecule of oxygen and give 2 molecules of steam.

∴ by Avogadro's Hypothesis,

2 vols. of hydrogen require 1 vol. of oxygen and give 2 vols. of steam.

There are 41·0 c.c. of oxygen and 95·6 c.c. of hydrogen, so that there is more hydrogen than the oxygen can combine with.

41 c.c. of oxygen require 82 c.c. of hydrogen and give 82 c.c. of steam.

∴ the total volume after sparking will be 82 c.c. (steam) *plus* 13·6 c.c. (unused hydrogen);

i.e. total residual volume = 95·6 c.c.

N.B. Observe that this calculation could be worked much more shortly as follows:

$$2H_2 + O_2 = 2H_2O \text{ (steam)}.$$

∴ volume of steam produced = volume of hydrogen used.

∴ only change in volume = volume of oxygen used.

In this case, *all* the oxygen is used,

∴ final volume of gases = original volume of hydrogen;
= 70 c.c. at N.T.P.
= 95·6 c.c. at 100° C. 760 mm.

14. Calculate the weight and the volume of dry sulphur dioxide, measured at 15° C., and 745 mm. pressure, required to convert 40 gm. of caustic soda into normal sodium sulphite. What weight of sodium sulphite is produced? (D.).

The equation is,

$$2NaOH + SO_2 = Na_2SO_3 + H_2O.$$

∴ 2 × 40 gm. of caustic soda require 22·4 litres of sulphur dioxide at N.T.P.

∴ 40 gm. of caustic soda require 11·2 litres of sulphur dioxide at N.T.P.

11·2 litres at N.T.P. become

$$\frac{11{\cdot}2 \times 288 \times 760}{273 \times 745} \text{ litres at } 15^\circ \text{ C. } 745 \text{ mm.,}$$
$$= 12{\cdot}1 \text{ litres.}$$

∴ volume of sulphur dioxide required = 12·1 litres.

From the equation,

2 × 40 gm. of caustic soda give 126 gm. of sodium sulphite,

∴ 40 gm. " " " " 63 " " " "

∴ weight of sodium sulphite formed = 63 gm.

15. A compound was found to contain: carbon 58·06 per cent, hydrogen 6·45 per cent, oxygen 12·90 per cent, and nitrogen 22·58 per cent. Calculate the simplest formula for the compound.

What further data would you require to ascertain the correct formula of the compound? (D.)

$$\textit{Carbon} \quad \frac{58{\cdot}06}{12} = 4{\cdot}84$$

$$\textit{Hydrogen} \quad \frac{6{\cdot}45}{1} = 6{\cdot}45$$

$$\textit{Oxygen} \quad \frac{12 \cdot 90}{16} = 0 \cdot 81$$

$$\textit{Nitrogen} \quad \frac{22 \cdot 58}{14} = 1 \cdot 61$$

$$\therefore C : H : O : N \text{ as } 4 \cdot 84 : 6 \cdot 45 : 0 \cdot 81 : 1 \cdot 61$$
$$= 6 : 8 : 1 : 2$$
$$\therefore \underline{\text{simplest formula} = C_6H_8ON_2.}$$

To ascertain the correct formula, the molecular weight of the compound (or some data from which the molecular weight may be calculated) must be known.

16. Nickel carbonyl, $Ni(CO)_4$, is completely decomposed to metallic nickel and carbon monoxide when its vapour is passed through a hot tube. Calculate the weight of metallic nickel, and a volume of carbon monoxide measured at 12° C. and 740 mm. pressure, which can be obtained from 20 gm. of nickel carbonyl. (D.)

The equation is:

$$Ni(CO)_4 = Ni + 4CO.$$
$$Ni = 59; \; C = 12; \; O = 16.$$

$\therefore 59 + 4(12 + 16) = 171 =$ M.W. of nickel carbonyl.

171 gm. of nickel carbonyl yield $4 \times 22 \cdot 4$ litres of carbon monoxide at N.T.P.

$\therefore$ 20 gm. of nickel carbonyl yield $\frac{4 \times 22 \cdot 4 \times 20}{171}$ litres of carbon monoxide at N.T.P.

This volume at 12° C. and 740 mm. will become

$$\frac{4 \times 22 \cdot 4 \times 20 \times 285 \times 760}{171 \times 273 \times 740}$$
$$= 11 \cdot 3 \text{ litres.}$$

$\therefore$ volume of carbon monoxide obtainable $= 11 \cdot 3$ litres.

Also,

171 gm. of nickel carbonyl yield 59 gm. of nickel,

$\therefore$ 20 gm. " " " " $\frac{59 \times 20}{171}$ " "

$$= 6 \cdot 9 \text{ gm.}$$

$\therefore$ weight of nickel obtainable $= 6 \cdot 9$ gm.

14. Calculate the weight and the volume of dry sulphur dioxide, measured at 15° C., and 745 mm. pressure, required to convert 40 gm. of caustic soda into normal sodium sulphite. What weight of sodium sulphite is produced? (D.).

The equation is:

$$2NaOH + SO_2 = Na_2SO_3 + H_2O.$$

∴ 2 × 40 gm. of caustic soda require 22·4 litres of sulphur dioxide at N.T.P.

∴ 40 gm. of caustic soda require 11·2 litres of sulphur dioxide at N.T.P.

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$$= 12 \cdot 1 \text{ litres.}$$

∴ volume of sulphur dioxide required = 12·1 litres.

From the equation,

2 × 40 gm. of caustic soda give 126 gm. of sodium sulphite,

∴ 40 gm. " " " " 63 " " " "

∴ weight of sodium sulphite formed = 63 gm.

15. A compound was found to contain: carbon 58·06 per cent, hydrogen 6·45 per cent, oxygen 12·90 per cent, and nitrogen 22·58 per cent. Calculate the simplest formula for the compound.

What further data would you require to ascertain the correct formula of the compound? (D.)

$$\textit{Carbon} \quad \frac{58 \cdot 06}{12} = 4 \cdot 84$$
$$\textit{Hydrogen} \quad \frac{6 \cdot 45}{1} = 6 \cdot 45$$

$$\textit{Oxygen} \quad \frac{12 \cdot 90}{16} = 0 \cdot 81$$

$$\textit{Nitrogen} \quad \frac{22 \cdot 58}{14} = 1 \cdot 61$$

$$\therefore C : H : O : N \text{ as } 4 \cdot 84 : 6 \cdot 45 : 0 \cdot 81 : 1 \cdot 61$$
$$= 6 : 8 : 1 : 2$$
$$\therefore \underline{\text{simplest formula} = C_6H_8ON_2.}$$

To ascertain the correct formula, the molecular weight of the compound (or some data from which the molecular weight may be calculated) must be known.

16. Nickel carbonyl, $Ni(CO)_4$, is completely decomposed to metallic nickel and carbon monoxide when its vapour is passed through a hot tube. Calculate the weight of metallic nickel, and a volume of carbon monoxide measured at 12° C. and 740 mm. pressure, which can be obtained from 20 gm. of nickel carbonyl. (D.)

The equation is:

$$Ni(CO)_4 = Ni + 4CO.$$
$$Ni = 59; \; C = 12; \; O = 16.$$
$$\therefore 59 + 4(12 + 16) = 171 = \text{M.W. of nickel carbonyl.}$$

171 gm. of nickel carbonyl yield 4 × 22·4 litres of carbon monoxide at N.T.P.

$\therefore$ 20 gm. of nickel carbonyl yield $\frac{4 \times 22 \cdot 4 \times 20}{171}$ litres of carbon monoxide at N.T.P.

This volume at 12° C. and 740 mm. will become

$$\frac{4 \times 22 \cdot 4 \times 20 \times 285 \times 760}{171 \times 273 \times 740}$$
$$= 11 \cdot 3 \text{ litres.}$$
$$\therefore \underline{\text{volume of carbon monoxide obtainable} = 11 \cdot 3 \text{ litres.}}$$

Also,

171 gm. of nickel carbonyl yield 59 gm. of nickel,

$\therefore$ 20 gm. ,, ,, ,, ,, $\frac{59 \times 20}{171}$,, ,,

$$= 6 \cdot 9 \text{ gm.}$$
$$\therefore \underline{\text{weight of nickel obtainable} = 6 \cdot 9 \text{ gm.}}$$

14. Calculate the weight and the volume of dry sulphur dioxide, measured at 15° C., and 745 mm. pressure, required to convert 40 gm. of caustic soda into normal sodium sulphite. What weight of sodium sulphite is produced? (D.)

The equation is:

$$2NaOH + SO_2 = Na_2SO_3 + H_2O.$$

∴ 2 × 40 gm. of caustic soda require 22·4 litres of sulphur dioxide at N.T.P.

∴ 40 gm. of caustic soda require 11·2 litres of sulphur dioxide at N.T.P.

11·2 litres at N.T.P. become

$$\frac{11{\cdot}2 \times 288 \times 760}{273 \times 745} \text{ litres at } 15^\circ \text{ C. } 745 \text{ mm.,}$$
$$= 12{\cdot}1 \text{ litres.}$$

∴ volume of sulphur dioxide required = 12·1 litres.

From the equation,

2 × 40 gm. of caustic soda give 126 gm. of sodium sulphite,

∴ 40 gm. " " " " 63 " " " "

∴ weight of sodium sulphite formed = 63 gm.

15. A compound was found to contain: carbon 58·06 per cent, hydrogen 6·45 per cent, oxygen 12·90 per cent, and nitrogen 22·58 per cent. Calculate the simplest formula for the compound.

What further data would you require to ascertain the correct formula of the compound? (D.)

$$\textit{Carbon} \quad \frac{58{\cdot}06}{12} = 4{\cdot}84$$

$$\textit{Hydrogen} \quad \frac{6{\cdot}45}{1} = 6{\cdot}45$$

$$\textit{Oxygen} \quad \frac{12 \cdot 90}{16} = 0 \cdot 81$$

$$\textit{Nitrogen} \quad \frac{22 \cdot 58}{14} = 1 \cdot 61$$

$$\therefore C : H : O : N \text{ as } 4 \cdot 84 : 6 \cdot 45 : 0 \cdot 81 : 1 \cdot 61$$
$$= 6 : 8 : 1 : 2$$
$$\therefore \underline{\text{simplest formula} = C_6H_8ON_2.}$$

To ascertain the correct formula, the molecular weight of the compound (or some data from which the molecular weight may be calculated) must be known.

16. Nickel carbonyl, $Ni(CO)_4$, is completely decomposed to metallic nickel and carbon monoxide when its vapour is passed through a hot tube. Calculate the weight of metallic nickel, and a volume of carbon monoxide measured at 12° C. and 740 mm. pressure, which can be obtained from 20 gm. of nickel carbonyl. (D.)

The equation is:

$$Ni(CO)_4 = Ni + 4CO.$$
$$Ni = 59;\ C = 12;\ O = 16.$$
$$\therefore 59 + 4(12 + 16) = 171 = \text{M.W. of nickel carbonyl.}$$

171 gm. of nickel carbonyl yield $4 \times 22 \cdot 4$ litres of carbon monoxide at N.T.P.

$\therefore$ 20 gm. of nickel carbonyl yield $\frac{4 \times 22 \cdot 4 \times 20}{171}$ litres of carbon monoxide at N.T.P.

This volume at 12° C. and 740 mm. will become

$$\frac{4 \times 22 \cdot 4 \times 20 \times 285 \times 760}{171 \times 273 \times 740}$$
$$= 11 \cdot 3 \text{ litres.}$$

$\therefore$ <u>volume of carbon monoxide obtainable = 11·3 litres.</u>

Also,

171 gm. of nickel carbonyl yield 59 gm. of nickel,

$\therefore$ 20 gm. „ „ „ „ $\frac{59 \times 20}{171}$ „ „

$$= 6 \cdot 9 \text{ gm.}$$

$\therefore$ <u>weight of nickel obtainable = 6·9 gm.</u>

17. State Gay-Lussac's Law of Volumes. What use was made of this law by Avogadro?

A mixture of 20 c.c. of hydrogen and methane is exploded with an excess of oxygen; the residual gas contracts 12 c.c. on being treated with potassium hydroxide solution. Calculate the percentage composition of the mixture. (C.L.)

See p. 70. Avogadro used this law as a basis for his celebrated Hypothesis (pp. 71-2).

Equations:

$$CH_4 + 2O_2 = CO_2 + 2H_2O.$$
$$2H_2 + O_2 = 2H_2O.$$

The residual gases consists of carbon dioxide and excess of oxygen (since the steam will have condensed). Carbon dioxide is soluble in potassium hydroxide solution, while oxygen is not. The contraction is therefore due to the carbon dioxide, which consequently occupies 12 c.c.

But, from the equation,

1 molecule of carbon dioxide is given by 1 molecule of methane.

$\therefore$ by Avogadro's Hypothesis,

1 volume of carbon dioxide is given by 1 volume of methane,

$\therefore$ 12 c.c. ,, ,, ,, are ,, ,, 12 c.c. ,, ,,

$\therefore$ volume of methane in 20 c.c. of original mixture = 12 c.c.,

and volume of hydrogen must therefore have been 8 c.c.

$\therefore$ *percentage* composition of the mixture by volume is:

Methane, 60,

Hydrogen, 40.

18. Explain what is meant by the term equivalent weight of an element. What is the relationship between the equivalent weight and the atomic weight?

A metal has a specific heat of 0·114; on reduction 1·286 and 1·430 gm. of two different oxides each

yielded 1·00 gm. of the metal. Calculate the valency of the metal in the two oxides and suggest their formulae. (C.L.)

See p. 34.

If the specific heat of the metal is 0·114, then by Dulong and Petit's Law (p. 34), its atomic weight must be about $\frac{6 \cdot 4}{0 \cdot 114}$, i.e. about 56.

In the *first oxide*,

0·286 gm. oxygen combine with 1 gm. of metal,

$\therefore$ 8 gm. " " " $\frac{1 \times 8}{0 \cdot 286}$ " "

= 28 gm. of metal.

$\therefore$ in this oxide the equivalent of the metal is 28

$$\text{But } valency = \frac{atomic\ weight}{equivalent},$$

$\therefore$ in this oxide, approximate valency $= \frac{56}{28}$

$= \underline{2.}$

This must, therefore, be the true valency, and the formula of the first oxide is $\underline{MO}$ (if M is the symbol for one atom of the metal).

In the *second oxide*,

0·430 gm. oxygen combine with 1 gm. of metal,

$\therefore$ 8 gm. " " " $\frac{1 \times 8}{8 \cdot 430}$ " "

= 18·6 gm. of metal.

$$\text{But } valency = \frac{atomic\ weight}{equivalent},$$

$\therefore$ in this oxide, approximate valency $= \frac{56}{18 \cdot 6}$

= nearly 3.

$\therefore$ true valency here is $\underline{3,}$ and the formula of the second oxide is $\underline{M_2O_3}$.

CHAPTER XI

MISCELLANEOUS PROBLEMS: WITH HINTS FOR ANSWERS

1. Two grams of water are subjected to the following reactions: (*a*) decomposed by an electric current, (*b*) acted upon by sodium, (*c*) passed in the form of steam over heated magnesium. Explain the reactions which take place and calculate the volume of gas (reduced to 0° and 760 mm.) produced in each case.

(L.M.)

Hints:

(*a*) $2H_2O = 2H_2 + O_2$ ∴ 36 gm. water give 44·8 litres of hydrogen and 22·4 litres of oxygen at N.T.P.

(*b*) $2Na + 2H_2O = 2NaOH + H_2$ ∴ here 36 gm. water give 22·4 litres of hydrogen at N.T.P.

(*c*) $Mg + H_2O = MgO + H_2$ ∴ here 18 gm. water give 22·4 litres of hydrogen at N.T.P.

Note that the answers to (*b*) and (*c*) can be now written down directly when the answer to (*a*) has been calculated.

2. 1 gm. of a mixture of zinc and zinc oxide, when dissolved in dilute sulphuric acid, yielded 200 c.c. of hydrogen measured at 25° C. and 740 mm. pressure. Calculate the percentage of zinc in the mixture.

(O. and C.)

Hints:

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$
$$ZnO + H_2SO_4 = ZnSO_4 + H_2O.$$

Therefore only the zinc will displace hydrogen as gas, and

from the first equation we see that 65 gm. zinc displace 22·4 litres of hydrogen at N.T.P.,

$$\text{i.e. } \frac{22{,}400 \times 298 \times 760}{273 \times 740} \text{ c.c. at } 25^\circ \text{ C. } 740 \text{ mm.}$$

Calculate the weight of zinc that would displace 200 c.c. of hydrogen at 25° C. 740 mm. This will be the weight of zinc in 1 gm. of the mixture, and the percentage weight will be 100 times as great.

3. Explain what is meant by 'water of crystallization.'

A hydrated salt was found to contain 20·72 per cent of sodium, 14·41 of sulphur, and 64·86 of water. Deduce its formula. (O. and C.)

Hints:

(i) See *A Junior Chemistry*, p. 111.

(ii) The formula may be calculated in the usual way (pp. 46–7), but dividing 64·86 by 18, the M.W. of water. Then

$$\frac{20{\cdot}72}{23} : \frac{14{\cdot}41}{32} : \frac{64{\cdot}86}{18}$$

will give the ratio of atoms of sodium to atoms of sulphur to molecules of water of crystallization, i.e., it will yield the values of x, y, and z, in the empirical formula $Na_xS_y.zH_2O$.

4. How may sodium hydroxide be prepared from washing soda (sodium carbonate)? 3·9 gm. washing soda crystals were dissolved in water and the solution made up to 250 c.c.; 27·3 c.c. of decinormal sulphuric acid solution exactly neutralized 25 c.c. of this solution. Calculate (*a*) the percentage weight of anhydrous sodium carbonate in the crystals, (*b*) the number of molecules of water of crystallization united with a molecule of sodium carbonate. (B.)

Hints:

(i) See *A Junior Chemistry*, p. 290.

(ii) 25 c.c. of the washing-soda solution = 27·3 c.c. $N/10$ sulphuric acid, therefore the washing-soda solution is $\frac{27 \cdot 3}{25} \times N/10$.

But $N/10$ sodium carbonate contains 5·3 gm. Na_2CO_3 per litre, therefore the washing-soda solution contains $\frac{27 \cdot 3}{25} \times 5 \cdot 3$ gm. Na_2CO_3 per litre. Also, from the figures, it contains $\frac{3 \cdot 9 \times 1000}{250}$ gm. washing-soda per litre.

(iii) Or, alternatively,

27·3 c.c. $N/10$ sulphuric acid = 25 c.c. soda solution
= 0·39 gm. washing-soda.

But 27·3 c.c. $N/10$ sulphuric acid = $\frac{5 \cdot 3 \times 27 \cdot 3}{1000}$ gm. Na_2CO_3. This is therefore the weight of Na_2CO_3 in 0·39 gm. washing-soda.

(iv) To get (*b*), calculate weight of water combined with 106 i.e. $(2 \times 23 + 12 + 3 \times 16)$ gm. Na_2CO_3 and divide by 18 i.e. $(2 \times 1 + 16)$.

5. 1 litre of marsh gas at S.T.P. weighs 0·72 gm.; 1 litre of acetylene weighs 1·17 gm. Show that these figures enable one to state that the formula of the former is CH_4 and not C_2H_8, while that of the latter is C_2H_2 and not CH.

Quote Avogadro's Rule, and show how it was applied in obtaining your answer. (O.L.)

Hints:

(i) By Avogadro's 'Rule,' Avogadro's Hypothesis is meant. This hypothesis is sometimes incorrectly known as Avogadro's Law.

(ii) If the formula for marsh gas were C_2H_8, 22·4 litres of it at S.T.P. would weigh $2 \times 12 + 8 = 32$ gm.

(iii) If the formula for acetylene were CH, 22·4 litres of it at S.T.P. would weigh $12 + 1 = 13$ gm.

(iv) Avogadro's 'Rule' is used in the above statements as follows: If the molecules of marsh gas and acetylene weigh 32 and 13 times, respectively, as much as the molecule of hydrogen, we assume that 32 gm. of marsh gas and 13 gm. of acetylene, each weight containing as many molecules as 2 gm. hydrogen, would (Avogadro's Hypothesis) occupy the same volume as the latter at the same temperature and pressure, e.g. 22·4 litres at N.T.P.

6. State the Law of the Combination of Gases by Volume, and show how it may be explained in the light of Avogadro's Hypothesis.

If a mixture of 50 c.c. of carbon monoxide and 100 c.c. of air were exploded, what would be the composition of the residual mixture of gases? (All volumes to be taken as measured at the same temperature and pressure.) (L.M.)

Hints:

(i) See *A Revision Course in Chemistry*, pp. 15–18.

(ii) $2CO + O_2 = 2CO_2$.

∴ carbon monoxide requires half its own volume of oxygen, and the volume of carbon dioxide formed equals the volume of carbon monoxide taken.

(iii) 50 c.c. CO require 25 c.c. oxygen (from i).

(iv) 100 c.c. air contain only 21 c.c. oxygen.

(v) ∴ only 42 c.c. of CO can be burned.

(vi) The 79 c.c. of nitrogen take no part in the action.

7. 0·5 gm. of a metal gave 494 c.c. of hydrogen measured moist at 11° C. under a pressure of 753 mm. The specific heat of the metal is 0·25. What is its atomic weight? (L.M.)

Hints:

(i) Calculate rough A.W. from Dulong and Petit's Law.

(ii) Correct volume of hydrogen to N.T.P., not forgetting to *subtract* aqueous vapour pressure at 11° C. from 753 mm.

(iii) 1 litre of hydrogen at N.T.P. weighs 0·09 gm.

(iv) Find weight of hydrogen evolved, and calculate number of grams of metal required to give 1 gm. hydrogen. This is the equivalent.

(v) Equivalent × valency = true atomic weight, and the valency must be a whole number.

8. Hydrogen was passed over heated cupric oxide, and the latter was converted into metal. When 5·2 gm. of the oxide were completely changed, 1·2 gm. of water was obtained. What is the equivalent of the metal? How would you confirm your result, using the metal obtained? (O. and C.)

Hints:

(i) All the oxygen in the water formed must have come from the 5·2 gm. of cupric oxide.

(ii) Water contains $\frac{8}{9}$ of its weight of oxygen.

(iii) ∴ weight of oxygen in 5·2 gm. of cupric oxide is $\frac{8}{9} \times 1{\cdot}2$ gm.

(iv) Weight of copper in 5·2 gm. oxide $= 5{\cdot}2 - (\frac{8}{9} \times 1{\cdot}2)$ gm.

(v) Calculate weight of copper that would combine with 8 gm. oxygen.

(vi) Confirmation: Take the metal, weigh it, convert it into cupric oxide (*via* copper nitrate) and weigh the cupric oxide formed.

9. You are given some potassium chlorate from which part of the oxygen has been driven by heat.

What experiments would you do to show that the solid contains (*a*) oxygen, (*b*) a chloride?

If the solid loses on further strong heating one per cent of its weight, calculate the percentage of potassium chloride in it. (D.)

Hints:

(*a*) Heat it further and test for evolved oxygen.

(*b*) Heat with distilled water to dissolve. To a little of the solution add nitric acid and silver nitrate solution. A chloride gives a white ppt. of silver chloride, AgCl.

(*c*) $2KClO_3 = 2KCl + 3O_2$.

$\therefore$ 245 gm. lose $3 \times 32 = 96$ gm.

(*d*) If 96 gm. are lost from 245 gm.

then 1 gm. is lost from $\frac{245}{96}$ gm.

10. The equivalent of oxygen is 8, its atomic weight is 16 and its molecular weight is 32, whilst the equivalent of sodium is 23, its atomic weight is 23 and its molecular weight is 23. Explain what is meant by these figures.

Assuming that the equivalent of zinc is 32·5, describe in detail a laboratory method of finding the percentage of zinc in a commercial sample of zinc dust. (B.)

Hints:

(i) See *A Revision Course in Chemistry*, pp. 23, 44, 38.

(ii) The chief impurity in zinc dust is zinc oxide, ZnO. In this question, assume that the zinc dust is entirely composed of zinc and zinc oxide, and cf. *Hints* to Q. 2 in this chapter.

11. How are (*a*) water gas, (*b*) producer gas obtained on a large scale? What are the chief constituents of the gases?

100 c.c. of a sample of producer gas became 98 c.c. when treated with caustic soda solution. The 98 c.c. when exploded with exactly the right amount of oxygen to burn it completely gave a mixture of gases. This mixture, when treated with caustic soda, diminished by 31 c.c., 67 c.c. of undissolved gas remaining.

From the above facts deduce as far as possible the composition of the gas. (D.)

Hints:

(a) See *A Junior Chemistry*, pp. 196, 206.

(b) See *A Junior Chemistry*, p. 206.

(c) Caustic soda solution absorbs carbon dioxide, a constant constituent of producer gas.

(d) The other constituents of producer gas may be taken as carbon monoxide and nitrogen. Nitrogen does not explode with oxygen, carbon monoxide does, when the mixture is sparked.

(e) $2CO + O_2 = 2CO_2$.

∴ carbon monoxide requires half its own volume of oxygen and gives its own volume of carbon dioxide.

12. Define the term *equivalent*, and describe, *in outline only*, FOUR methods of determining the equivalents of metals.

0·26 gm. of a metal were dissolved in nitric acid and then precipitated as the metallic chloride by addition of decinormal sodium chloride solution. It was found that 25·4 c.c. of the latter solution were required. What is the equivalent of the metal? (L.M.)

Hints:

(i) See *A Junior Chemistry*, pp. 359–67.

(ii) The equivalent of the metal is the number of grams of it required to react (ultimately) with 10 litres of $N/10$ sodium chloride solution. Don't go the long way round.

13. Calculate the volume of dry carbon dioxide, measured at 17° C., and 764 mm. pressure, theoretically required to convert 20 gm. of caustic potash into (*a*) normal potassium carbonate, (*b*) acid potassium carbonate. Give, with reasons, any experiments you would make to distinguish between solutions of these materials. (D.)

Hints:

(i) $2KOH + CO_2 = K_2CO_3 + H_2O$.

(ii) $KOH + CO_2 = KHCO_3$.

(iii) Hence volume in (*b*) can be obtained simply by doubling result calculated for (*a*).

(iv) From (i), 22·4 litres of carbon dioxide at N.T.P. will convert $2(39 + 16 + 1) = 112$ gm. KOH into normal potassium carbonate.

(v) Distinctions. (*a*) On boiling, K_2CO_3 solution is unaffected; $KHCO_3$ solution yields CO_2.
(*b*) With litmus, K_2CO_3 solution is alkaline; $KHCO_3$ solution is practically neutral.

14. State Gay-Lussac's Law of Volumes and give three distinct examples which illustrate the law.

10 c.c. of hydrogen, 5 c.c. of carbon monoxide, and 20 c.c. of oxygen are exploded together in a eudiometer; determine the volumetric composition of the resulting gas, (*a*) if the experiment is conducted at room temperature, (*b*) if the temperature is constant and higher than 100° C. during the whole experiment. (C.L.)

100 c.c. of a sample of producer gas became 98 c.c. when treated with caustic soda solution. The 98 c.c. when exploded with exactly the right amount of oxygen to burn it completely gave a mixture of gases. This mixture, when treated with caustic soda, diminished by 31 c.c., 67 c.c. of undissolved gas remaining.

From the above facts deduce as far as possible the composition of the gas. (D.)

Hints:

(*a*) See *A Junior Chemistry*, pp. 196, 206.

(*b*) See *A Junior Chemistry*, p. 206.

(*c*) Caustic soda solution absorbs carbon dioxide, a constant constituent of producer gas.

(*d*) The other constituents of producer gas may be taken as carbon monoxide and nitrogen. Nitrogen does not explode with oxygen, carbon monoxide does, when the mixture is sparked.

(*e*) $2CO + O_2 = 2CO_2$.

$\therefore$ carbon monoxide requires half its own volume of oxygen and gives its own volume of carbon dioxide.

12. Define the term *equivalent*, and describe, *in outline only*, FOUR methods of determining the equivalents of metals.

0·26 gm. of a metal were dissolved in nitric acid and then precipitated as the metallic chloride by addition of decinormal sodium chloride solution. It was found that 25·4 c.c. of the latter solution were required. What is the equivalent of the metal? (L.M.)

Hints:

(i) See *A Junior Chemistry*, pp. 359–67.

CHAPTER XII

MISCELLANEOUS PROBLEMS

1. What is meant by (*a*) a 'saturated solution,' (*b*) a super-saturated solution?

100 gm. of water dissolve the following weights of ammonium chloride at the temperatures named:

Temperature	0°	10°	20°	30°	40°	50°	60°	80°	100°
Substance	28·4	32·8	37·3	41·3	46·2	50·6	55·0	64·0	72·8 gm.

Construct the solubility curve of the substance, and from the curve determine the solubility of ammonium chloride at 24° and at 70°. (L.M.)

2. What volume of gas measured at 17° C. and at 580 mm. of mercury will be evolved when 4·8 gm. of calcium are dissolved in hydrochloric acid?

Describe a method of collecting and measuring the gas so evolved. (O. and C.)

3. If 200 c.c. of a solution of caustic soda are neutralized by 100 c.c. of a solution of hydrochloric acid containing 7·3 gm. of HCl per litre, what is the strength of the caustic soda solution? (B.)

4. The equivalent or combining weight of mercury may be determined by heating a weighed amount of mercuric oxide, and measuring the volume of oxygen

Hints:

(i) At room temperature, the steam produced will condense and the volume of the liquid water may be neglected.

(ii) Above 100° C., the steam will remain as gas.

(iii) $2H_2 + O_2 = 2H_2O$.

∴ 2 vols. of hydrogen require 1 vol. of oxygen [and give (ii) 2 volumes of steam].

(iv) $2CO + O_2 = 2CO_2$.

∴ 2 volumes of carbon monoxide require 1 volume of oxygen and give 2 volumes of carbon dioxide.

Temperature in °C.	*Solubility of potassium nitrate*
0	12·5
10	22
20	32
40	64
50	85
70	138

(B.)

8. State the law which expresses the relationship between the volume and the temperature for gases (Charles's Law).

25 c.c. of a gas at 27° exerts a pressure of 800 mm. To what temperature must it be heated in order that it may exert a pressure of 950 mm., the volume being kept constant? (L.M.)

9. State Avogadro's Hypothesis and show that the Law of the Combination of Gases by Volume is a necessary consequence of it.

What contraction in volume occurs when a mixture of equal volumes of hydrogen and air is exploded at 15° and the products are brought to the original temperature and pressure? (O. and C.)

10. Hot concentrated sulphuric acid is allowed to react with (*a*) sulphur, (*b*) zinc, (*c*) potassium nitrate, (*d*) potassium bromide, and (*e*) copper sulphate crystals. State any changes which occur and explain them.

What volume of gas would be theoretically obtained at 15° C. and 800 mm., if in the first reaction the weight of the sulphur was 20 gm?

(S = 32.)

(B.)

evolved on heating, at some given temperature and pressure.

Describe in detail how you would carry out this experiment, pointing out all the precautions you would take to obtain an accurate result.

3·24 gm. of mercuric oxide under these conditions were found to yield 187 c.c. oxygen at 17° C. and 725 mm. pressure.

Calculate the equivalent of mercury. (C.W.B.)

5. Describe the preparation of a solution of hydrogen peroxide in water and give an account of its more important properties.

Hydrogen peroxide is decomposed catalytically according to the equation: $2H_2O_2 = 2H_2O + O_2$. What volume of oxygen, measured at 20° C. and 756 mm., would be evolved when 50 c.c. of a solution of hydrogen peroxide, containing 20 gm. per litre, were decomposed? (C.L.)

6. Describe methods for preparing oxygen (*a*) in the laboratory, (*b*) on the industrial scale.

Calculate the volume of oxygen at 17° C. and 720 mm. obtainable by heating to a high temperature 1 gm. of pure $KClO_3$. (O. and C.)

7. What do you understand by the 'solubility' of a substance in water?

From the data given below, plot the solubility curve of potassium nitrate in water, and find the solubility of this substance at 30° C.

A compound contains by weight nitrogen = 35·0 per cent, hydrogen = 5·0 per cent, and oxygen = 60·0 per cent. Calculate the formula of the compound, and indicate the action of (*a*) heat, (*b*) caustic soda, (*c*) strong sulphuric acid upon it. Give the equations for the reactions you mention. (C.W.B.)

16. State the Law of Multiple Proportions.

What experiments would you carry out to show the truth of this law in the case of two oxides of lead?

The two chlorides of mercury contain respectively 15·07 per cent and 26·20 per cent of chlorine. Show that these figures are in accordance with the above law. (D.)

17. 'When gases react together they do so in volumes which bear a simple ratio to one another, and to the volume of the gaseous product.' Illustrate this statement with *three* examples and show, in any *one* case, how it may be proved experimentally.

20 c.c. of ammonia are mixed with 20 c.c. of oxygen and the mixture exploded. What volume of gas remains and of what does it consist? (The temperature, 15° C., and the pressure are constant during the experiment.) (B.)

18. Explain the terms 'atomic weight,' 'equivalent weight,' and point out the relation between them.

A metallic chloride contains 60 per cent of metal. Calculate the equivalent weight of the metal.

(O. and C.)

19. On analysis it was found that 0·49 gm. of a

11. How would you determine the equivalent weight of a metal insoluble in hydrochloric acid?

From one gram of a metal 1·75 gm. of the metallic chloride can be prepared. What is the equivalent weight of the metal? (D.)

12. Carefully define the terms—atomic weight and equivalent or combining weight. What is the connection between these two quantities?

Certain elements have more than one equivalent. Explain why this may be the case.

4·665 gm. of a metallic chloride gave off, under suitable treatment, 336 c.c. of chlorine measured at N.T.P. Calculate the equivalent of the metal. (C.W.B.)

13. What weight of pure sodium bicarbonate, $NaHCO_3$, is necessary to convert 100 c.c. of decinormal hydrochloric acid into a solution of sodium chloride? (O. and C.)

14. How woud you prepare and collect a few jars of ethylene gas?

10 c.c. of a gaseous hydrocarbon are exploded with 100 c.c. of oxygen. The residual gas, on cooling, is found to measure 95 c.c., of which 20 c.c. are absorbed by caustic soda and the remainder by pyrogallic acid [i.e. alkaline pyrogallol]. Determine the formula of the hydrocarbon. (C.L.)

15. Having given the percentage composition by weight of a compound and the atomic weights of the elements contained therein, explain carefully how to find the formula of the compound.

litre) for exact neutralization. Determine the percentage of $CaCO_3$ in the original mixture. (C.L.)

24. Carefully sketch and describe the apparatus you would use to determine the volume of carbon dioxide evolved when approximately 1 gm. of pure chalk is decomposed by an acid. Calculate the volume of gas measured at 13° C. and 741 mm. pressure which should be obtained from 1·08 gm. chalk, when acted upon by an acid. (B.)

25. Define the terms equivalent weight of an element and atomic weight. What weight of cupric oxide would be reduced to copper by heating it in the hydrogen which results when 3 gm. of zinc are dissolved in sulphuric acid? (O. and C.)

26. Define *valency*. If elements X, Y, and Z have valencies of 1, 2, and 3 respectively, what are the most probable formulae of compounds of X and Y, X and Z, Y and Z?

0·3 gm. of a diad [i.e. bivalent] metal reacted completely with water, setting free 168 c.c. of hydrogen measured at N.T.P. What is the atomic weight of the metal? (D.)

27. State Gay-Lussac's Law of the Combination of Gases by Volume.

In the case of *either* the combination of hydrogen and chlorine, *or* the combination of carbon monoxide and oxygen, give practical details for proving that the law is true.

20 c.c. of a mixture of oxygen and nitrogen are mixed

metallic chloride contained 0·165 gm. of the metal. Determine the *equivalent weight of the metal.*

What experimental methods are available for determining the atomic weight of a metal when the equivalent weight is known? (L.M.)

20. State the Law of Multiple Proportions. Describe, giving all necessary practical details, an experiment to verify the law.

A metal forms two chlorides which contain respectively 55·90 per cent and 65·53 per cent of chlorine. Show how these results may be used to illustrate the Law of Multiple Proportions. (C.W.B.)

21. Describe the preparation and properties of nitric acid.

What weight of nitric acid could be prepared from one ton of potassium nitrate? (O. and C.)

22. What do you understand by the 'vapour density' of a substance?

0·337 gm. of a substance displaced in a Victor Meyer's apparatus 31·6 c.c. of air measured over water at 18°, the height of the barometer being 774·5 mm. What is its molecular weight? (L.M.)

23. What is understood by the term 'normal solution of hydrochloric acid'?

1 gm. of calcium carbonate having calcium sulphate as an impurity is dissolved in 250 c.c. of normal hydrochloric acid. 25 c.c. of the resulting liquid is found to require 31·2 c.c. of a solution of sodium hydroxide (containing 30 gm. of sodium hydroxide per

heated to constant weight. What volume of hydrochloric acid containing 10 gm. per litre of HCl will be required to react with the solid product?

(O. and C.)

32. How many c.c. of a solution of sodium hydroxide containing 20 gm. per litre would be required to neutralize 100 c.c. of a solution of sulphuric acid containing 25 gm. per litre? (B.)

33. State Graham's Law of Gaseous Diffusion. How would you show experimentally that hydrogen diffuses more rapidly than air?

The ratio of the rate of diffusion of a certain gas to that of oxygen is 8 : 9·6. What is the molecular weight of the gas? (L.M.)

34. What do you understand by the 'equivalent weight' of an element?

0·33 gm. of a certain metal, when dissolved in hydrochloric acid, yielded 442 c.c. of hydrogen measured at 16° C. and 75 cm. pressure. Calculate the equivalent weight of the metal. Sketch an apparatus you would use to carry out the above experiment, and state what precautions you would take to ensure a good result. (C.W.B.)

35. A metal forms two oxides; 1·000 gm. of each oxide contains 0·239 and 0·385 gm. of oxygen respectively.

Determine the equivalent of the metal in each oxide and show that these figures are in agreement with the Law of Multiple Proportions. (C.L.)

with 30 c.c. of hydrogen, and the mixture is exploded. If the resulting volume of gas is 8 c.c., find the percentage of oxygen present in the original volume of gas. (C.W.B.)

28. State Avogadro's Hypothesis and show that the Law of the Combination of Gases by Volume is a necessary consequence of its truth.

What contraction in volume occurs when a mixture of equal volumes of hydrogen and air is exploded and the products brought to the original temperature and pressure? (O. and C.)

29. 0·785 gm. of a chloride of mercury yielded, on reduction, 0·667 gm. of mercury.

0·678 gm. of another chloride of mercury yielded, on reduction, 0·501 gm. of mercury.

Calculate the equivalent weight of mercury in each case and comment on the results obtained. (C.L.)

30. Define the terms 'gaseous density,' 'molecular weight.'

Describe a simple experimental method for determining gaseous density.

The vapour densities of the two chlorides of an element are respectively 63·5 and 81·25. In a gram molecular weight of each chloride there is 56 gm. of the element. Show that the composition of the chlorides is in accordance with the Law of Multiple Proportions. (D.)

31. Calculate the weight and volume (at N.T.P.) of gas liberated when 10 gm. of calcium carbonate are

heated to constant weight. What volume of hydrochloric acid containing 10 gm. per litre of HCl will be required to react with the solid product?

(O. and C.)

32. How many c.c. of a solution of sodium hydroxide containing 20 gm. per litre would be required to neutralize 100 c.c. of a solution of sulphuric acid containing 25 gm. per litre? (B.)

33. State Graham's Law of Gaseous Diffusion. How would you show experimentally that hydrogen diffuses more rapidly than air?

The ratio of the rate of diffusion of a certain gas to that of oxygen is 8 : 9·6. What is the molecular weight of the gas? (L.M.)

34. What do you understand by the 'equivalent weight' of an element?

0·33 gm. of a certain metal, when dissolved in hydrochloric acid, yielded 442 c.c. of hydrogen measured at 16° C. and 75 cm. pressure. Calculate the equivalent weight of the metal. Sketch an apparatus you would use to carry out the above experiment, and state what precautions you would take to ensure a good result. (C.W.B.)

35. A metal forms two oxides; 1·000 gm. of each oxide contains 0·239 and 0·385 gm. of oxygen respectively.

Determine the equivalent of the metal in each oxide and show that these figures are in agreement with the Law of Multiple Proportions. (C.L.)

with 30 c.c. of hydrogen, and the mixture is exploded. If the resulting volume of gas is 8 c.c., find the percentage of oxygen present in the original volume of gas. (C.W.B.)

28. State Avogadro's Hypothesis and show that the Law of the Combination of Gases by Volume is a necessary consequence of its truth.

What contraction in volume occurs when a mixture of equal volumes of hydrogen and air is exploded and the products brought to the original temperature and pressure? (O. and C.)

29. 0·785 gm. of a chloride of mercury yielded, on reduction, 0·667 gm. of mercury.

0·678 gm. of another chloride of mercury yielded, on reduction, 0·501 gm. of mercury.

Calculate the equivalent weight of mercury in each case and comment on the results obtained. (C.L.)

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31. Calculate the weight and volume (at N.T.P.) of gas liberated when 10 gm. of calcium carbonate are

heated to constant weight. What volume of hydrochloric acid containing 10 gm. per litre of HCl will be required to react with the solid product?

(O. and C.)

32. How many c.c. of a solution of sodium hydroxide containing 20 gm. per litre would be required to neutralize 100 c.c. of a solution of sulphuric acid containing 25 gm. per litre? (B.)

33. State Graham's Law of Gaseous Diffusion. How would you show experimentally that hydrogen diffuses more rapidly than air?

The ratio of the rate of diffusion of a certain gas to that of oxygen is 8 : 9·6. What is the molecular weight of the gas? (L.M.)

34. What do you understand by the 'equivalent weight' of an element?

0·33 gm. of a certain metal, when dissolved in hydrochloric acid, yielded 442 c.c. of hydrogen measured at 16° C. and 75 cm. pressure. Calculate the equivalent weight of the metal. Sketch an apparatus you would use to carry out the above experiment, and state what precautions you would take to ensure a good result. (C.W.B.)

35. A metal forms two oxides; 1·000 gm. of each oxide contains 0·239 and 0·385 gm. of oxygen respectively.

Determine the equivalent of the metal in each oxide and show that these figures are in agreement with the Law of Multiple Proportions. (C.L.)

with 30 c.c. of hydrogen, and the mixture is exploded. If the resulting volume of gas is 8 c.c., find the percentage of oxygen present in the original volume of gas. (C.W.B.)

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What contraction in volume occurs when a mixture of equal volumes of hydrogen and air is exploded and the products brought to the original temperature and pressure? (O. and C.)

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0·678 gm. of another chloride of mercury yielded, on reduction, 0·501 gm. of mercury.

Calculate the equivalent weight of mercury in each case and comment on the results obtained. (C.L.)

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The vapour densities of the two chlorides of an element are respectively 63·5 and 81·25. In a gram molecular weight of each chloride there is 56 gm. of the element. Show that the composition of the chlorides is in accordance with the Law of Multiple Proportions. (D.)

31. Calculate the weight and volume (at N.T.P.) of gas liberated when 10 gm. of calcium carbonate are

40. Explain the meaning of 'equivalent weight,' and 'atomic weight.'

A metal forms a chloride containing 73·8 per cent of the metal. Calculate the equivalent weight of the metal. (O. and C.)

41. What is the equivalent weight of an element? Describe a method which could be used for finding the equivalent weight of a metal *either* by synthesis *or* analysis of its chloride.

A metal forms two anhydrous chlorides. 2·27 gm. and 2·90 gm. of the chlorides can be produced respectively from 1 gm. of the metal. The equivalent weight of chlorine is 35·5. Calculate the two equivalent weights of the metal. (D.)

42. Explain and illustrate the terms 'element' and 'equivalent.'

Find the atomic weight of a divalent metal, 1 gm. of which yields 1·658 gm. of oxide. (O. and C.)

43. State the Law of Multiple Proportions and show how it may be deduced from Dalton's Atomic Theory.

Water and hydrogen peroxide have the following compositions by weight:

Water: Hydrogen, 11·11 per cent. Oxygen, 88·89 per cent.
Hydrogen peroxide: Hydrogen, 5·88 per cent. Oxygen, 94·12 per cent.

Show that these figures are in agreement with the law. (L.M.)

44. Define the term 'equivalent.' 1·402 gm. of a

36. Given some pure sodium carbonate crystals, how would you find the strength of a given solution of sulphuric acid?

1 gm. of anhydrous sodium carbonate neutralized 50 c.c. of a solution of sulphuric acid. What was the strength of the acid solution in gm. per litre?

(O. and C.)

37. Given slaked lime, caustic potash, manganese dioxide and a concentrated solution of hydrochloric acid, what experiments would you make to prepare (*a*) bleaching powder, (*b*) a specimen of potassium chlorate free from chloride?

What volume of chlorine at 17° C. and 750 mm. pressure has been used in the formation of 10 gm. of potassium chlorate? (D.)

38. You are provided with some iron filings, sulphur, and concentrated sulphuric acid. State the preparation of three gases in which these chemicals are used. Give the practical details of preparing and collecting several jars of *one* of the compound gases.

What volume of this gas could be theoretically obtained at 15° C. and 700 mm. if the weight of the solid substance used was 50 gm.? (B.)

39. Describe an apparatus by which a constant supply of hydrogen sulphide gas could be obtained.

What volume of hydrogen sulphide gas, measured at 15° C. and 750 mm. pressure, would precipitate 0·5 gm. of cupric sulphide, if passed through a solution of cupric sulphate and completely absorbed? (C.L.)

TABLE OF ATOMIC WEIGHTS

Element	Symbol	Exact Atomic Weight	Approximate Atomic Weight
Aluminium	Al	27·0	27
Antimony	Sb	121·8	122
Argon	A	39·94	40
Arsenic	As	74·96	75
Barium	Ba	137·37	137
Bismuth	Bi	209·0	209
Boron	B	10·82	11
Bromine	Br	79·92	80
Cadmium	Cd	112·40	112
Calcium	Ca	40·07	40
Carbon	C	12·00	12
Chlorine	Cl	35·46	35·5
Chromium	Cr	52·01	52
Cobalt	Co	58·94	59
Copper	Cu	63·57	63·6
Gold	Au	197·2	197
Helium	He	4·00	4
Hydrogen	H	1·008	1
Iodine	I	126·93	127
Iron	Fe	55·84	56
Krypton	Kr	82·92	83
Lead	Pb	207·20	207
Magnesium	Mg	24·32	24
Manganese	Mn	54·93	55
Mercury	Hg	200·6	201
Neon	Ne	20·2	20
Nickel	Ni	58·68	59
Nitrogen	N	14·01	14
Oxygen	O	16·00	16
Phosphorus	P	31·02	31

metal displaced 0·051 gm. of hydrogen from a dilute acid. What is the equivalent of the metal? (B.)

45. Give a careful definition of the term 'equivalent' or 'combining weight' of an element.

With the necessary practical details describe *two distinct* methods for finding the equivalent of copper.

3·2 gm. of a metal react exactly with 13·07 gm. of sulphuric acid. Calculate the equivalent of the metal. (C.W.B.)

46. What is the equivalent weight of an element? How is it related to the atomic weight of the element?

0·375 gm. of zinc on solution in hydrochloric acid gave 135·3 c.c. of hydrogen at 15° C. and 780 mm. pressure. What is the equivalent weight of zinc? (O. and C.)

47. Describe an experiment to determine the composition of steam by volume. State Gay-Lussac's Law of Volumes and Avogadro's Hypothesis and hence show how you could establish the equation $2H_2 + O_2 = 2H_2O$.

50 c.c. of a mixture of equal volumes of hydrogen and oxygen are exploded in a eudiometer tube. Find the volume and composition of the remaining gas measured at the same pressure, if the whole experiment is performed (*a*) at 100° C., (*b*) at 0° C. (B.)

48. Calculate (*a*) the volume of dry hydrogen, measured at 17° C., and 720 mm. pressure, required to reduce 26·33 gm. of cupric oxide to metal, (*b*) the weights of copper and of water obtained. [Cu = 63.] (D.)

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Element	Symbol	Exact Atomic Weight	Approximate Atomic Weight
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Bismuth . . .	Bi	209·0	209
Boron	B	10·82	11
Bromine . . .	Br	79·92	80
Cadmium . . .	Cd	112·40	112
Calcium . . .	Ca	40·07	40
Carbon . . .	C	12·00	12
Chlorine . . .	Cl	35·46	35·5
Chromium . . .	Cr	52·01	52
Cobalt	Co	58·94	59
Copper . . .	Cu	63·57	63·6
Gold	Au	197·2	197
Helium . . .	He	4·00	4
Hydrogen . . .	H	1·008	1
Iodine	I	126·93	127
Iron	Fe	55·84	56
Krypton . . .	Kr	82·92	83
Lead	Pb	207·20	207
Magnesium . . .	Mg	24·32	24
Manganese . . .	Mn	54·93	55
Mercury . . .	Hg	200·6	201
Neon	Ne	20·2	20
Nickel	Ni	58·68	59
Nitrogen . . .	N	14·01	14
Oxygen . . .	O	16·00	16
Phosphorus . . .	P	31·02	31

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Bromine	Br	79·92	80
Cadmium	Cd	112·40	112
Calcium	Ca	40·07	40
Carbon	C	12·00	12
Chlorine	Cl	35·46	35·5
Chromium	Cr	52·01	52
Cobalt	Co	58·94	59
Copper	Cu	63·57	63·6
Gold	Au	197·2	197
Helium	He	4·00	4
Hydrogen	H	1·008	1
Iodine	I	126·93	127
Iron	Fe	55·84	56
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Lead	Pb	207·20	207
Magnesium	Mg	24·32	24
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TABLE OF AQUEOUS VAPOUR PRESSURE

Temperature ° C.	Pressure in mm.	Temperature ° C.	Pressure in mm.
0	4·6	11	9·8
1	4·9	12	10·5
2	5·3	13	11·2
3	5·7	14	12·0
4	6·1	15	12·8
5	6·5	16	13·6
6	7·0	17	14·5
7	7·5	18	15·5
8	8·0	19	16·5
9	8·6	20	17·5
10	9·2		

Element	Symbol	Exact Atomic Weight	Approximate Atomic Weight
Platinum . . .	Pt	195·2	195
Potassium . . .	K	39·1	39
Radon	Rn	222·5	222·5
Selenium . . .	Se	79·2	79
Silicon	Si	28·3	28
Silver	Ag	107·88	108
Sodium . . .	Na	23·00	23
Strontium . . .	Sr	87·63	88
Sulphur . . .	S	32·06	32
Tin	Sn	118·7	118
Xenon	Xe	130·2	130
Zinc	Zn	65·38	65

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Temperature ° C.	Pressure in mm.	Temperature ° C.	Pressure in mm.
0	4·6	11	9·8
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2	5·3	13	11·2
3	5·7	14	12·0
4	6·1	15	12·8
5	6·5	16	13·6
6	7·0	17	14·5
7	7·5	18	15·5
8	8·0	19	16·5
9	8·6	20	17·5
10	9·2		

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3	5·7	14	12·0
4	6·1	15	12·8
5	6·5	16	13·6
6	7·0	17	14·5
7	7·5	18	15·5
8	8·0	19	16·5
9	8·6	20	17·5
10	9·2		

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Sodium	Na	23·00	23
Strontium	Sr	87·63	88
Sulphur	S	32·06	32
Tin	Sn	118·7	118
Xenon	Xe	130·2	130
Zinc	Zn	65·38	65

25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4814	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	5	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	5	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8

LOGARITHMS

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11	0414	0433	0492	0331	0569	0607	0643	0682	0719	0755	4 8 12 13 4 7 11 13	19 19	23 27 31 33 22 26 30 33
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3 7 11 14 3 7 10 14	18 17	21 23 28 32 20 24 27 31
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15	1761	1790	1818	1847	1873	1903	1931	1939	1957	2014	3 6 9 11 3 5 8 11	14 14	17 20 23 26 16 19 22 25
16	2041	2068	2093	2122	2148	2175	2201	2227	2253	2279	3 3 8 11 3 3 8 10	14 13	16 19 22 24 13 18 21 23
17	2304	2330	2355	2380	2405	2430	2433	2480	2504	2529	3 3 8 10 2 3 7 10	13 12	13 18 20 23 13 17 19 22
18	2553	2377	2601	2613	2648	2672	2693	2718	2742	2763	2 3 7 9 2 3 7 9	12 11	14 16 19 21 14 16 18 21
19	2788	2810	2833	2836	2878	2900	2923	2943	2967	2989	2 4 7 9 2 4 6 8	11 11	13 16 18 20 13 15 17 19
20	3010	3032	3054	3073	3096	3118	3139	3160	3181	3201	2 4 6 8	11	13 15 17 19
21	3222	3243	3263	3284	3304	3324	3343	3365	3385	3404	2 4 6 8	10	12 14 16 18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2 4 6 8	10	12 14 15 17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2 4 6 7	9	11 13 13 17
24	3802	3820	3838	3836	3874	3892	3909	3927	3943	3962	2 4 5 7	9	11 12 14 16

75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	3	4	4
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	3	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

LOGARITHMS—*continued*

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51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5

·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4

·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	2	3	5	7	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7161	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8933	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8933	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9934	9977	2	5	7	9	11	14	16	18	20

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

ANTILOGARITHMS—*continued*

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·31	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	3	3	6	7
·32	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	3	3	6	7
·33	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	3	6	6	7
·34	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	3	6	6	7
·33	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	3	6	7	7
·36	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	3	6	7	8
·37	3713	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	3	6	7	8
·38	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·39	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	3	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4053	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4236	1	2	3	4	3	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4343	4333	1	2	3	4	3	6	7	8	9
·64	4365	4373	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·63	4467	4477	4487	4498	4508	4519	4529	4539	4350	4360	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4643	4636	4667	1	2	3	4	3	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4773	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4873	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	3023	5035	5047	5058	5070	5082	5093	5103	3117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12

ANSWERS

ANSWERS

CHAPTER I. GAS LAWS, pp. 3, 7, 9

1. (*a*) 30; (*b*) 6; (*c*) 240; (*d*) 120; (*e*) 600; (*f*) 50 c.c.
2. (*a*) 2; (*b*) 8; (*c*) 40; (*d*) 0·4; (*e*) 0·8; (*f*) 400 atmospheres
3. (*a*) 10,000; (*b*) 100; (*c*) 2,000; (*d*) 200; (*e*) 4,000; (*f*) 800 cu. ft.

4. 10,000	5. 38 c.c.	6. 360 c.c.
7. 3,167 mm.	8. 11 c.c.	9. 28·3 c.c.
10. 9 atmospheres	11. 300 mm.	12. 99 gm.
13. 240 c.c.	14. 300 c.c.	15. 20 c.c.
16. 110 c.c.	17. 133 c.c.	18. 34·1 c.c.
19. 666·7 c.c.	20. Oxygen; 133 c.c.	21. 193° C.
22. 546°	23. The latter; 4·5 c.c.	
24. 27·3 c.c.	25. 941 mm.	26. 283° C.
27. 500 c.c.	28. 27·7 c.c.	29. 1,440 c.c.
30. 57·6 c.c.	31. 116·9 c.c.	32. 15·0 c.c.
33. 191 c.c.	34. 600 yards	35. 8 c.c.
36. 25·9 c.c.	37. 27·3 c.c.	

CHAPTER II. EQUIVALENTS, p. 18

1. 12·16	2. 32·5	3. 20
4. 9·3 gm.	5. 6	6. 32
7. 9	8. 29·5	9. 100
10. 103·5	11. 23	12. 20
13. 15·9	14. 212	15. 1·12 litres; 1·12 litres
16. 31·8	17. 12·16	18. 9
19. 108	20. 77·8; 103·5	21. 53·3; 6
22. 113	23. 21	24. (*a*) 52·9; (*b*) 20·2
25. 35·8		

ANSWERS

CHAPTER I. Gas Laws, pp. 5, 7, 9

1. (*a*) 30; (*b*) 6; (*c*) 240; (*d*) 120; (*e*) 600; (*f*) 50 c.c.
2. (*a*) 2; (*b*) 8; (*c*) 40; (*d*) 0·4; (*e*) 0·8; (*f*) 400 atmospheres
3. (*a*) 10,000; (*b*) 100; (*c*) 2,000; (*d*) 200; (*e*) 4,000; (*f*) 800 cu. ft.

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7. 3,167 mm.	8. 11 c.c.	9. 28·3 c.c.
10. 9 atmospheres	11. 300 mm.	12. 99 gm.
13. 240 c.c.	14. 300 c.c.	15. 20 c.c.
16. 120 c.c.	17. 135 c.c.	18. 34·1 c.c.
19. 666·7 c.c.	20. Oxygen; 133 c.c.	21. 193° C.
22. 546°	23. The latter; 4·5 c.c.	
24. 27·3 c.c.	25. 941 mm.	26. 283° C.
27. 500 c.c.	28. 27·7 c.c.	29. 1,440 c.c.
30. 57·6 c.c.	31. 116·9 c.c.	32. 15·0 c.c.
33. 191 c.c.	34. 600 yards	35. 8 c.c.
36. 25·9 c.c.	37. 27·3 c.c.	

CHAPTER II. Equivalents, p. 18

1. 12·16	2. 32·5	3. 20
4. 9·5 gm.	5. 6	6. 32
7. 9	8. 29·5	9. 100
10. 103·5	11. 23	12. 20
13. 15·9	14. 212	15. 1·12 litres; 1·12 litres
16. 31·8	17. 12·16	18. 9
19. 108	20. 77·8; 103·5	21. 53·3; 6
22. 115	23. 21	24. (*a*) 32·9; (*b*) 20·2
25. 35·8		

13. 181·8 gm. 14. 5 15. 11·2 litres
16. 1·23 gm. 17. 16·3 tons 18. 8·4 gm.
19. 50 lb. 20. 14·66 gm.; 5·34 gm. ammonia
21. Potassium 22. (a) 14·6; (b) 25·8; (c) 21·25; (d) 17·25; (e) 13·25; (f) 21 gm. 23. 1·64 gm.
24. 2·8 gm.; 10 gm. 25. 6·67 gm.; 23·67 gm.
26. 6·21 gm.; 0·54 gm. 27. 80
28. 96 lb. too little 29. 5833 c.c. 30. 16 c.c.
31. 11·2 litres; the same 32. 5,600 litres
33. 3,360 34. 5·6 litres hydrogen; 2·8 litres oxygen
35. 4·5 litres 36. 2·24 litres
37. 11·2 litres nitrogen weighing 14 gm.; 33·6 litres hydrogen weighing 3 gm. 38. (i) 56 c.c.; (ii) 56 c.c.
39. 882 c.c. 40. 44·8 litres 41. 15·6 litres
42. (a) 7·58; (b) 7·58; (c) 1·26 litres 43. 87
44. 205·3 gm. 45. 10·27 litres 46. 193·6 c.c.
47. 1,515 c.c. 48. 5·43 litres 49. 5,297 c.c.
50. 27·14 c.c.; 95·4; 190·8; 0·1764 gm.

CHAPTER VII. Solubilities and Solubility Curves, p. 67

1. 2·8 gm. 2. 28 gm. 4. 25; 94; 140 8. 56·2

CHAPTER VIII. Gas Analysis, p. 80

1. (i) 17; (ii) 64; (iii) 30; (iv) 44; (v) 36·5; (vi) 28; (vii) 44; (viii) 71; (ix) 32; (x) 48 gm.
2. (i) 11·2; (ii) 22·4; (iii) 224; (iv) 4·48; (v) 11·2; (vi) 11·2; (vii) 6·72; (viii) 44·8; (ix) 7·47; (x) 224 litres
3. (i) 50; (ii) 50; (iii) 100; (iv) 50; (v) 50 c.c.
4. (i) 200; (ii) 300; (iii) 400; (iv) 100; (v) 150; (vi) 50; (vii) 250; (viii) 150; (ix) 100; (x) 250 c.c.
5. (i) 160; (ii) 21·3; (iii) 7; (iv) 12·75; (v) 6·6; (vi) 0·28; (vii) 0·00415; (viii) 3,650; (ix) 38; (x) 238 gm.

CHAPTER III. Some Chemical Laws, p. 28

1. 2 : 1 2. 4 : 3 : 2 3. 1 : 2 : 3 : 4 : 5
4. 3 : 5 5. 1 : 2 6. 10 : 1
7. 1 : 7 8. 1·08 gm. lead in each case gives 1·16 gm. oxide
9. 3 : 1

CHAPTER IV. Molecular and Atomic Weights, p. 40

1. 35·5; 71 2. 17 3. 17 4. 44
5. (a) 4; (b) 48; (c) 36·5; (d) 93; (e) 342; (f) 246
6. 65·1 7. 125; 250 8. 118
9. 62·2 c.c. 10. 200 11. 163
12. 0·302; 29·25 13. 110 14. 82·7
15. 39 16. 71 17. 206
18. 63·6 19. 108 20. 16; 6; 96
21. 18·7; 3; 56·1; XCl_3 22. 200
23. 17·3; 26; 52 24. 80 25. 118; MCl_4
26. 14 27. 35·5

CHAPTER V. Formulae and Composition by Weight, p. 50

1. (i) K 31·8; Cl 29·0; O 39·2; (ii) Na 43·4; C 11·3; O 45·3; (iii) H 2·74; Cl 97·26; (iv) N 29·2; H 8·33; C 12·5; O 50.
2. (i) $Ca(OH)_2$; (ii) $CaCO_3$; (iii) FeS; (iv) $KHCO_3$; (v) KNO_3
3. (i) Na_2CO_3; (ii) $CuSO_4.5H_2O$; (iii) $ZnSO_4.7H_2O$; (iv) Pb_3O_4; (v) $K_2Cr_2O_7$ 4. CON_2H_4
5. AgCl 6. $C_2H_4Br_2$ 7. CH_5N

CHAPTER VI. Reacting Quantities from Equations, p. 54

1. 32 gm. 2. 24 gm. 3. 260 tons in each case
4. 202 lb.; less (170 lb.) 5. 60·7 6. 100 gm. nitrous oxide
7. 14·8 8. 36·9 per cent. 9. 28·8 gm.
10. 148 gm. 11. 3·9 gm. 12. 261 gm.

CHAPTER XII. Miscellaneous Problems, p. 117

1. 38·8; 59·4
2. 5·7 litres
3. $N/10$, i.e. 4 gm. per litre
4. 100
5. 355·5 c.c.
6. 507·5 c.c.
7. 46
8. 83° C.
9. 31·5 per cent
10. 42·1 litres
11. 47·3
12. 120
13. 0·84 gm.
14. C_2H_6
15. $N_2H_4O_3$, i.e. NH_4NO_3
16. Ratio is 1 : 2
17. 10 c.c. nitrogen and 5 c.c. oxygen
18. 53·25
19. 18·0
20. Ratio is 2 : 3
21. 0·624 ton
22. 255
23. 80
24. 262 c.c.
25. 3·67 gm.
26. 40
27. 70
28. 31·5 per cent
29. 200·6; 100·5. Results illustrate Law of Multiple Proportions
30. Ratio is 2 : 3
31. 4·4 gm.; 2·24 litres; 730 c.c.
32. 102 c.c.
33. 44·1
34. 89·7
35. 25·5; 12·8. Ratio 2 : 1
36. 18·5
37. 984 c.c.
38. Vol. of SO_2 formed from 50 gm. sulphur:

$$2H_2SO_4 + S = 3SO_2 + 2H_2O,$$
$$= 120·5 \text{ litres;}$$

hydrogen sulphide from 50 gm. FeS = 14·6 litres.

39. 125·2 c.c.
40. 100
41. 28·0; 18·7
42. 24·32
43. Ratio is 1 : 2
44. 27·5
45. 11·99
46. 51·65
47. (a) 25 c.c. steam; 12·5 c.c. oxygen: (b) 12·5 c.c. oxygen
48. (a) 8·37 litres; (b) 21 gm. copper; 6 gm. water

6. 50·5 7. 46·9 8. 60 c.c. NH_3; 1470 c.c. N; 4410 c.c. H
9. 21 per cent oxygen; 79 per cent nitrogen. 10. 80
11. (*a*) 79 c.c. N; 18 c.c. H; (*b*) 79 c.c. N; 18 c.c. H; 42 c.c. H_2O
12. 4 per cent. 13. 8·5 c.c. methane; 1·5 c.c. nitrogen
14. 40 per cent CO_2; 60 per cent CO 15. C_2H_4
16. C_2H_2 17. C_3H_8 18. 12CO; 12H; 8N
19. 57 20. 45 c.c. 21. 50

CHAPTER IX. VOLUMETRIC ANALYSIS, p. 88

1. (*a*) 49; (*b*) 36·5; (*c*) 63; (*d*) 40; (*e*) 56; (*f*) 53; (*g*) 143; (*h*) 45; (*i*) 63
2. (*a*) $N/10$; (*b*) $2N$; (*c*) N; (*d*) $N/5$; (*e*) $1·25 \times N/10$; (*f*) $2N$; (*g*) $N/5$; (*h*) $1·11 \times N$; (*i*) $0·79 \times N$
3. 60 4. 225
5. (*a*) 10 c.c.; (*b*) 100 c.c.; (*c*) 20 c.c.; (*d*) 200 c.c.; (*e*) 50 c.c.
6. (*a*) $\frac{28}{25} \times N/10$; (*b*) 1·9 gm. per litre 7. 18
8. $0·04 \times N$ 9. 200 c.c. 10. 1·58
11. 2·8 12. 100 13. 50
14. 72 15. 12·2 16. 90·6
17. Sulphate; 14·0 c.c. 18. 27·4 gm.
19. $x = 1$ 20. 3·15 gm.; 450 c.c. 21. 1·44 gm.
22. 136 23. 21·9 24. 1·01 gm.

CHAPTER X. MISCELLANEOUS PROBLEMS: WORKED EXAMPLES, p. 94

Examples worked in text.

CHAPTER XI. MISCELLANEOUS PROBLEMS: WITH HINTS FOR ANSWERS, p. 108

Answers not supplied to these examples.

CHAPTER XII. MISCELLANEOUS PROBLEMS, p. 117

1. 38·8; 59·4
2. 3·7 litres
3. $N/10$, i.e. 4 gm. per litre
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6. 507·5 c.c.
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8. 83° C.
9. 31·5 per cent
10. 42·1 litres
11. 47·3
12. 120
13. 0·84 gm.
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15. $N_2H_4O_3$, i.e. NH_4NO_3
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18. 53·25
19. 18·0
20. Ratio is 2 : 3
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22. 255
23. 80
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$$= 120·3 \text{ litres};$$

hydrogen sulphide from 50 gm. FeS = 14·6 litres.

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40. 100
41. 28·0; 18·7
42. 24·32
43. Ratio is 1 : 2
44. 27·5
45. 11·99
46. 31·65
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48. (*a*) 8·37 litres; (*b*) 21 gm. copper; 6 gm. water

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CONTENTS

My thanks are due to the following examining bodies, for permission to reproduce questions set in School Certificate and Matriculation Examinations: the University of London; the University of Bristol; the Oxford and Cambridge Schools Examination Board; the Joint Matriculation Board of the Northern Universities; the Central Welsh Board; the University of Durham School Examinations Board; the University of Cambridge Local Examinations Syndicate; and the Delegates of the Oxford Local Examinations.

I have also pleasure in thanking two of my pupils, J. M. M. Pinkerton and J. S. Pippard, for checking the answers: an exacting task which they undertook with delightful readiness.

E. J. HOLMYARD.

CLIFTON COLLEGE, BRISTOL.
February 1935.

CHAPTER I

THE GAS LAWS

Boyle's Law.—*The volume of a given mass of gas varies inversely as the pressure upon it, if the temperature is constant.*

$$V \propto \frac{1}{P} \text{ if T is constant;}$$
$$\text{or } PV = P'V' \text{ if T is constant.}$$

Charles's Law.—*The volume of a given mass of gas varies directly as the* ABSOLUTE *temperature, if the pressure is constant.*

$$V \propto T \text{ Abs. if P is constant;}$$
$$\text{or } VT' = V'T \text{ if P is constant.}$$

[Absolute temperature = Centigrade + 273.]

Third Law.—*The pressure of a given mass of gas varies directly as the* ABSOLUTE *temperature, if the volume is constant.*

$$P \propto T \text{ Abs. if V is constant;}$$
$$\text{or } PT' = P'T \text{ if V is constant.}$$

The Gas Equation (combining all three laws).—*For a given mass of gas, the product of the pressure and volume, divided by the* ABSOLUTE *temperature, is a constant.*

$$\frac{PV}{T} = \text{a constant, i.e. } \frac{PV}{T} = \frac{P'V'}{T'} = \frac{P''V''}{T''}, \text{ etc.}$$

[N.B.—The constant is usually represented by R, and the equation is then written PV = RT.]

NOTE

Letters in brackets—thus (L.M.)—after a question indicate that the question has been taken from a school certificate or matriculation paper.

B. = Bristol University.

C.L. = Cambridge Local.

C.W.B. = Central Welsh Board.

D. = Durham University.

J.M.B. = Joint Matriculation Board.

L.M. = London Matriculation.

O. and C. = Oxford and Cambridge Examination Board.

O.L. = Oxford Local.

(iv) Some nitrogen, occupying 246 c.c., is at a pressure of 1 atmosphere (= 760 mm.). If it is introduced into a evacuated globe of 2 litres capacity, what will be the pressure in the globe? (T constant.)

$$\begin{aligned} PV &= P'V' \\ \therefore 246 \times 760 &= x \times 2000 \\ \therefore x &= \frac{246 \times 760}{2000} \\ &= \underline{93{\cdot}5 \text{ mm.}} \end{aligned}$$

PROBLEMS.

A. **Boyle's Law.**—[Take temperature as constant throughout.]

[N.B. Nos. 1–4 to be worked by mental arithmetic.]

1. Some neon occupies 60 c.c. at 1 atmosphere pressure. What will be its volume at

(*a*) 2 atmospheres,
(*b*) 10 atmospheres,
(*c*) $\frac{1}{2}$ atmosphere,
(*d*) 380 mm.,
(*e*) 76 mm.,
(*f*) 1520 mm.?

2. A certain mass of nitrogen occupies 100 c.c. at 4 atmospheres pressure. What must the pressure be to make it occupy

(*a*) 200 c.c.,
(*b*) 50 c.c.,
(*c*) 10 c.c.,
(*d*) 1000 c.c.,
(*e*) 500 c.c.,
(*f*) 1 c.c.?

Standard or Normal Temperature and Pressure (S.T.P. or N.T.P.) are 0° C. and 760 mm.

One atmosphere is a pressure of 760 mm.

EXAMPLES.

A. Boyle's Law.

(i) 100 c.c. of hydrogen are at a pressure of 760 mm. What volume will the hydrogen occupy at 380 mm., if the temperature does not change?

Here the pressure is to be halved ($380 = \frac{760}{2}$), hence by Boyle's Law, the volume will be doubled. Therefore the volume of the hydrogen at 380 mm. will be 100×2 = <u>200 c.c.</u>

(ii) A volume of 300 c.c. of oxygen, measured at one atmosphere pressure, is to be compressed into a bottle of capacity 100 c.c. What pressure will be required, supposing the temperature to remain constant?

The volume is to be reduced to *one-third* of its original value; hence the final pressure must be three times the original pressure. The required pressure is therefore 1×3 = <u>3 atmospheres.</u>

(iii) 115 c.c. of chlorine are at 700 mm. pressure. What volume will the gas occupy at 280 mm. pressure, if T is constant?

$$PV = P'V'$$
$$\therefore 115 \times 700 = 280 \times x$$
$$\therefore x = \frac{115 \times 700}{280}$$
$$= \underline{287 \cdot 5 \text{ c.c.}}$$

the tap between them opened. What will be the final pressure throughout the two cylinders?

11. 3 litres of chlorine, measured at 700 mm. pressure, have to be compressed into a flask of 2100 c.c. capacity. What increase of pressure will be necessary?

12. A tube containing a gas at 1 atmosphere pressure weighed, inclusive of the contents, 100 gm. The same tube filled with the same gas at 2 atmospheres pressure weighed, inclusive of the contents, 101 gm. Find the weight of the tube empty.

EXAMPLES.

B. Charles's Law.

(i) 100 c.c. of oxygen are at a temperature of 0° C. The temperature is then raised to 273° C. What volume will the oxygen now occupy, if the pressure remains constant?

First, change the temperatures to the Absolute scale:

$$0^\circ \text{ C.} = 0 + 273 = 273^\circ \text{ Abs.}$$
$$273^\circ \text{ C.} = 273 + 273 = 546^\circ \text{ Abs.}$$

Therefore the Absolute temperature of the oxygen is to be doubled, and since the volume of a given mass of gas is directly proportional to its Absolute temperature, the volume also will be doubled.

The final volume of the oxygen is thus 100×2 = 200 c.c.

(ii) 125 c.c. of oxygen are at 17° C. What volume

3. Some helium occupies 1000 cubic feet at 760 mm. Calculate the volume it would occupy at

(a) 7·6 c.cm.,
(b) 7600 mm.,
(c) half an atmosphere,
(d) 5 atmospheres,
(e) 190 mm.,
(f) $1\frac{1}{4}$ atmospheres.

4. A cylinder of capacity 20 litres contains argon at a pressure of 100 atmospheres. How many flasks of 200 c.c. capacity could be filled from the cylinder, at one atmosphere pressure?

5. A gas occupies 37 c.c. at 760 mm. What will be its volume at 740 mm.?

6. A certain mass of oxygen has a volume of 380 c.c. at 720 mm. What volume will it have at Normal pressure (760 mm.)?

7. 100 c.c. of hydrogen at Normal pressure can be made to occupy 24 c.c. if the pressure is suitably altered. What must the new pressure be?

8. 88 c.c. of oxygen are at a pressure of 770 mm. The pressure is then raised to 880 mm. By how much will the volume of the oxygen diminish?

9. Calculate the volume at Standard pressure (760 mm.) of some carbon dioxide that occupies 28·5 c.c. at 755 mm.

10. A cylinder of 5 cu. ft. capacity contains hydrogen at a pressure of 3 atmospheres. A second cylinder, of 10 cu. ft. capacity, contains hydrogen at a pressure of 12 atmospheres. The two cylinders are connected and

PROBLEMS.

B. **Charles's Law.**—[Take pressure as constant throughout.]

[N.B. Nos. 13–16 to be worked by mental arithmetic.]

13. 120 c.c. of gas are at 273° Abs. The temperature is raised to 546° Abs. What is the new volume of the gas?

14. 100 c.c. of air are at 0° C. The temperature is raised to 546° C. What is the new volume of the gas?

15. Some helium occupies 2 c.c. at 27·3° Abs. The temperature is then raised to 0° C. What is the volume of the helium at this temperature?

16. A specimen of hydrogen occupies 240 c.c. at Normal temperature. What will be its volume at − 136·5° C.?

17. The volume of a sample of chlorine at 91° C. is 180 c.c. The temperature is lowered to 0° C. Find the final volume of the chlorine.

18. Some hydrogen occupies 36·0 c.c. at 15° C. Correct its volume to Normal temperature.

19. 1000 c.c. of oxygen are at a temperature of 27° C. Find the volume at − 73° C.

20. 546 c.c. of oxygen at 0° C. are heated to 127° C. 546 c.c. of nitrogen at 300° C. are heated to 427° C. Which gas will expand more, and by how much more?

21. Two litres of air are measured at 100° C. At what temperature (°C.) would the volume become 2½ litres?

22. 78 c.c. of neon are at 0° C. What rise in

will the gas occupy at 597° C., if the pressure does not change?

$$17^\circ \text{ C.} = 17 + 273 = 290^\circ \text{ Abs.}$$
$$597^\circ \text{ C.} = 597 + 273 = 870^\circ \text{ Abs.}$$

Thus the Absolute temperature has been increased in the ratio $\frac{870}{290}$ and the volume must, therefore, be increased in the same ratio.

$$\therefore \text{ final volume of oxygen } = 125 \times \frac{870}{290} = 125 \times 3$$
$$= \underline{375 \text{ c.c.}}$$

(iii) 125 c.c. of hydrogen are at 17° C. What volume will the gas occupy at 100° C., if the pressure is constant?

$$VT' = V'T$$
$$17^\circ \text{ C.} = 290^\circ \text{ Abs.}; 100^\circ \text{ C.} = 373^\circ \text{ Abs.}$$
$$\therefore 125 \times 373 = x \times 290$$
$$\therefore x = \frac{125 \times 373}{290}$$
$$= \underline{161 \text{ c.c.}}$$

(iv) 142 c.c. of helium are at 27° C. To what temperature (°C.) must the gas be heated in order that it may occupy 1000 c.c. at the same pressure?

$$VT' = V'T$$
$$27^\circ \text{ C.} = 300^\circ \text{ Abs.}$$
$$\therefore 142 \times x = 1000 \times 300$$
$$\therefore x = \frac{1000 \times 300}{142}$$
$$= 2113^\circ \textit{ Absolute,}$$
$$\text{i.e. } 2113 - 273 = \underline{1840^\circ \text{ Centigrade.}}$$

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ELEMENTARY CHEMICAL CALCULATIONS

PROBLEMS.

C. Third Law.

25. Some hydrogen is contained in a sealed glass tube. The pressure in the tube at 22° C. is 775 mm. If the tube is immersed in a bath of water at 85° C., what will the pressure in the tube then become?

26. A bulb contains neon at 0·1 mm. pressure, the temperature being 10° C. If the pressure of the gas is required to be 0·2 mm., by how much must the temperature be raised?

PROBLEMS ON THE GAS LAWS IN GENERAL.

27. A gas occupies 100 c.c. at − 245·7° C. and 380 mm. Find its volume at N.T.P.

28. A specimen of carbon monoxide has a volume of 30 c.c. at 15° C. 740 mm. Correct this volume to S.T.P.

29. Some nitrogen occupies 120 c.c. at N.T.P. If the temperature is raised to 546° C. and the pressure lowered to 190 mm., what will be the final volume of the gas?

30. A sample of ammonia has a volume of 109·2 c.c. at 0° C. 760 mm. Find its volume at 15° C. 1520 mm.

31. 125 c.c. of chlorine are at 17° C. 755 mm. What volume will the gas occupy at S.T.P.?

32. 15·7 c.c. of hydrogen are at −10° C. and 700 mm. Calculate the volume of the gas at N.T.P.

temperature (°C.) is necessary to make the gas occupy 234 c.c.?

23. One specimen of carbon dioxide occupied 100 c.c. at 27° C. and another occupied 228·9 c.c. at 390° C. Which specimen would occupy the greater volume at 100° C.? What would be the difference between the two final volumes?

24. Some hydrogen occupies 29 c.c. at 17° C. Correct its volume to Standard temperature.

EXAMPLES.

C. Third Law.

(i) 100 c.c. of gas are at a pressure of 700 mm. and a temperature of 17° C. If the temperature is raised to 307° C., what will the new pressure be, assuming the volume to remain constant?

$$PT' = P'T$$
$$\therefore 700 \times (307 + 273) = P' \times (273 + 17)$$
$$\therefore P' = \frac{700 \times 580}{290}$$
$$= \underline{1400 \text{ mm.}}$$

(ii) A certain volume of gas is at 30° C. 740 mm. The volume is kept constant, and the gas is heated until its pressure is 2 atmospheres. At what temperature will this pressure be reached?

$$PT' = P'T$$
$$\therefore 740 \times T' = (2 \times 760) \times (273 + 30)$$
$$\therefore T' = \frac{1520 \times 303}{740}$$
$$= 622$$
$$\therefore \text{temperature in °C.} = 622 - 273$$
$$= \underline{349.}$$

EXAMPLE.

Some oxygen, collected over water, occupied 35 c.c. at 6° C. 765 mm. Find its volume *dry* at N.T.P.

Pressure of aqueous vapour at 6° C. = 7 mm.

$\therefore$ true pressure on the oxygen = 765 − 7 = 758 mm.

$$\therefore \text{volume at N.T.P.} = \frac{35 \times 758 \times 273}{760 \times 279} = \underline{34{\cdot}2 \text{ c.c.}}$$

36. Calculate the volume, dry, at N.T.P., of a gas that occupies 28 c.c. at 14° C. 750 mm. when saturated with water-vapour.

37. Some air was collected over water at 17° C., and was found to occupy 29 c.c. when the barometer stood at 774·5 mm. Find its volume, dry, at S.T.P.

33. 207 c.c. of coal-gas are at 15° C. 740 mm. Find the volume of the gas at 0° C. 760 mm.

34. A lorry contains oxygen cylinders in which the pressure of the gas is 120 atmospheres (temperature 15° C.). The cylinders would burst if the pressure reached 200 atmospheres. The lorry takes fire and the temperature of the cylinders rises at the rate of 2° C. per second. The driver can run 100 yards in 16 seconds. How far away from the lorry could he run before the explosion occurred?

35. A cylinder contains a glass stopper and a certain volume of gas, the total volume of the stopper and gas being 141 c.c. at 13° C. 747 mm. On raising the pressure to 775 mm., without change of temperature, the total volume diminishes to 136·2 c.c. Find the volume of the stopper.

NOTE.—If a gas is allowed to remain in contact with sufficient water, it will become saturated with water-vapour. In this case the effective pressure of the dry gas itself is the external pressure on the moist gas *minus* the pressure of aqueous vapour (water-vapour) at the temperature concerned. Thus, suppose some hydrogen is saturated with water-vapour at 14° C., and that the moist gas is at a pressure of 755 mm. Then the effective pressure of the hydrogen is 755 mm. *minus* the pressure of aqueous vapour at 14° C. This can be found from the tables (cf. p. 131); it is 12 mm.; therefore the true pressure of the hydrogen is 755 − 12, i.e. 743 mm.

(*c*) 200 gm. of mercury combine with 16 gm. of oxygen; hence the equivalent of mercury is $\frac{200 \times 8}{16}$ = 100.

(*d*) When treated with zinc, and suitably diluted, 98 gm. of sulphuric acid yield 2 gm. of hydrogen; hence the equivalent of sulphuric acid is $\frac{98}{2} = 49$.

(*e*) *When it reacts as an oxidizing agent*, 316 gm. of potassium permanganate will yield 80 gm. of oxygen; therefore the equivalent of potassium permanganate is $\frac{316 \times 8}{80} = 31{\cdot}6$.

EXAMPLES.

(i) Sodium hydride contains 4·17 per cent of hydrogen. Find the equivalent of sodium.

4·17 gm. hydrogen combine with 95·83 gm. sodium. ∴ 1 gm. hydrogen combines with $\frac{95{\cdot}83}{4{\cdot}17}$ gm. sodium = 23·0 gm. sodium

Hence equivalent of sodium = 23·0.

(ii) 0·36 gm. of a metal liberated 367 c.c. of hydrogen from a dilute acid, collected over water at 16° C. 738 mm. Calculate the equivalent of the metal.

Vapour pressure of water at 16° C. = 13·6 mm.

∴ pressure on hydrogen = 738 − 13·6
= 724·4 mm.

Corrected volume of hydrogen $= \frac{367 \times 273 \times 724{\cdot}4}{289 \times 760}$
= 330·5 c.c.

Weight of this hydrogen $= \frac{330{\cdot}5 \times 0{\cdot}09}{1000}$ gm.

CHAPTER II

EQUIVALENTS

The Equivalent[1] *of a substance is the number of units of weight of that substance that will combine with or displace* 1 *of the same units of weight of hydrogen or* 8 *of the same units of weight of oxygen.*

The equivalents on the two standards are approximately the same, since the equivalent of oxygen on the hydrogen standard is approximately 8.

[A substance may have more than one equivalent, according to the ways in which it reacts. Thus in red copper oxide the equivalent of copper is 63·6, while in the black oxide it is 31·8. But in all such cases, the various equivalents of the same substance are related to one another in a very simple numerical way: thus, in the example given, 63·6 = 31·8 × 2.]

Examples.

(*a*) 35·5 gm. of chlorine combine with 1 gm. of hydrogen; therefore the equivalent of chlorine is 35·5.

(*b*) 12 gm. (or oz. or lb., etc.) of carbon will combine with 4 gm. (or oz. or lb., etc.) of hydrogen. Hence the equivalent of carbon is $\frac{12}{4} = 3$.

[1] Sometimes known as 'equivalent weight,' though this term is not strictly correct, since the equivalent of a substance is a ratio, not a weight.

$1{\cdot}15 - 1{\cdot}00 = 0{\cdot}15$ gm. = weight of oxygen combining with $1{\cdot}00$ gm. of metal.

If $0{\cdot}15$ gm. of oxygen combine with 1 gm. of metal, then 8 gm. of oxygen combine with $\frac{1 \times 8}{0{\cdot}15}$

$= 53{\cdot}3$ gm. of metal.

$\therefore$ equivalent of metal = $\underline{53{\cdot}3}$.

(vi) The equivalent of copper in black copper oxide is $31{\cdot}75$. Calculate the percentage composition of the oxide.

Since the equivalent of copper is $31{\cdot}75$, $31{\cdot}75$ gm. of copper would be combined with 8 gm. of oxygen.

$\therefore$ $(31{\cdot}75 + 8) = 39{\cdot}75$ gm. of the oxide contain 8 gm. of oxygen, and thus 100 gm. of the oxide contain $\frac{8 \times 100}{39{\cdot}75}$ gm. of oxygen

$= 20{\cdot}1$ gm. oxygen.

Hence percentage composition of the oxide is

Cu, 79.9; O, $20{\cdot}1$.

(vii) $2{\cdot}5$ gm. of a metallic oxide are obtained from 2 gm. of metal. Calculate the equivalent of the metal.

If $0{\cdot}5$ gm. oxygen combine with 2 gm. metal, 8 gm. oxygen combine with $\frac{2 \times 8}{0{\cdot}5}$ gm. metal

$= 32$ gm.

$\therefore$ equivalent of metal = $\underline{32}$.

(viii) On heating lead in oxygen, the weight increases by $7{\cdot}73$ per cent. Calculate the equivalent of lead.

The increase in weight is due to the conversion of lead into lead oxide.

Hence $7{\cdot}73$ gm. oxygen combine with 100 gm. lead, $\therefore$ 8 gm. oxygen combine with $\frac{8 \times 100}{7{\cdot}73}$ gm. lead

$= 103{\cdot}5$ gm.

$\therefore$ equivalent of lead = $\underline{103{\cdot}5}$.

If $\frac{330 \cdot 5 \times 0 \cdot 09}{1000}$ gm. of hydrogen is liberated by 0·36 gm. metal, then 1 gm. of hydrogen is liberated by $\frac{0 \cdot 36 \times 1000}{330 \cdot 5 \times 0 \cdot 09}$

$= 12 \cdot 1$ gm. metal.

Hence equivalent of metal = 12·1.

(iii) The equivalent of calcium is 20. What weight of calcium would have to be dissolved in water to give 300 c.c. of hydrogen at N.T.P.?

20 gm. of calcium liberate 1 gm. of hydrogen (∵ equivalent of calcium is 20).

300 c.c. hydrogen at N.T.P. weigh $\frac{300}{1000} \times 0 \cdot 09$ gm.

$= 0 \cdot 027$ gm.

Since 1 gm. of hydrogen is liberated by 20 gm. of calcium, 0·027 gm. of hydrogen is liberated by $\frac{20 \times 0 \cdot 027}{1}$

$= 0 \cdot 54$ gm. calcium

(iv) 0·57 gm. of a metal yielded 105 c.c. of hydrogen, measured at 15° C. 740 mm. pressure. What is the equivalent of the metal?

105 c.c. at 15° C. 740 mm. become $\frac{105 \times 273 \times 740}{288 \times 760}$ at N.T.P.

$= 96 \cdot 9$ c.c.

1000 c.c. of hydrogen at N.T.P. weigh 0·09 gm.

∴ 96·9 " " " " $\frac{0 \cdot 09 \times 96 \cdot 9}{1000}$ gm.

Since $\frac{0 \cdot 09 \times 96 \cdot 9}{1000}$ gm. hydrogen are liberated by 0·57 gm. metal,

∴ 1 gm. hydrogen would be liberated by $\frac{0 \cdot 57 \times 1000}{0 \cdot 09 \times 96 \cdot 9}$ metal,

$= 65 \cdot 4$ gm.

Hence equivalent of metal = 65·4.

(v) 1·00 gm. of a metal yielded 1·15 gm. of the metallic oxide. Calculate the equivalent of the metal.

$1{\cdot}15 - 1{\cdot}00 = 0{\cdot}15$ gm. = weight of oxygen combining with $1{\cdot}00$ gm. of metal.

If $0{\cdot}15$ gm. of oxygen combine with 1 gm. of metal, then 8 gm. of oxygen combine with $\frac{1 \times 8}{0{\cdot}15}$

$= 53{\cdot}3$ gm. of metal.

$\therefore$ equivalent of metal $= \underline{53{\cdot}3}$.

(vi) The equivalent of copper in black copper oxide is $31{\cdot}75$. Calculate the percentage composition of the oxide.

Since the equivalent of copper is $31{\cdot}75$, $31{\cdot}75$ gm. of copper would be combined with 8 gm. of oxygen.

$\therefore$ $(31{\cdot}75 + 8) = 39{\cdot}75$ gm. of the oxide contain 8 gm. of oxygen, and thus 100 gm. of the oxide contain $\frac{8 \times 100}{39{\cdot}75}$ gm. of oxygen

$= 20{\cdot}1$ gm. oxygen.

Hence percentage composition of the oxide is

$\underline{Cu, 79{\cdot}9;\ O, 20{\cdot}1.}$

(vii) $2{\cdot}5$ gm. of a metallic oxide are obtained from 2 gm. of metal. Calculate the equivalent of the metal.

If $0{\cdot}5$ gm. oxygen combine with 2 gm. metal, 8 gm. oxygen combine with $\frac{2 \times 8}{0{\cdot}5}$ gm. metal

$= 32$ gm.

$\therefore$ equivalent of metal $= \underline{32.}$

(viii) On heating lead in oxygen, the weight increases by $7{\cdot}73$ per cent. Calculate the equivalent of lead.

The increase in weight is due to the conversion of lead into lead oxide.

Hence $7{\cdot}73$ gm. oxygen combine with 100 gm. lead, $\therefore$ 8 gm. oxygen combine with $\frac{8 \times 100}{7{\cdot}73}$ gm. lead

$= 103{\cdot}5$ gm.

$\therefore$ equivalent of lead $= \underline{103{\cdot}5.}$

(ix) 0·84 gm. of a metallic oxide on reduction gave 0·73 gm. metal. Calculate the equivalent of the metal.

$$0·84 - 0·73 = 0·11 \text{ gm.} = \text{weight of oxygen.}$$

If 0·11 gm. oxygen combine with 0·73 gm. metal, then 8 gm. oxygen combine with $\frac{0·73 \times 8}{0·11}$ gm. metal

$$= 53·1 \text{ gm.}$$

$\therefore$ equivalent of metal $=$ <u>53·1.</u>

(x) 2 gm. of a certain metallic oxide when reduced in hydrogen yielded 0·252 gm. water. Calculate the equivalent of the metal.

Eight-ninths by weight of water is oxygen; hence weight of oxygen in 2 gm. of the oxide $= \frac{0·252 \times 8}{9}$

$$= 0·224 \text{ gm.}$$

$\therefore$ weight of metal $= 2 - 0·224 = 1·776$ gm.

If 0·224 gm. oxygen combine with 1·776 gm. metal, then 8 gm. oxygen combine with $\frac{1·776 \times 8}{0·224}$ gm. metal

$$= \underline{63·4}.$$

(xi) 0·374 gm. of a metal yielded 0·446 gm. of its oxide. What is the equivalent of the metal? Equivalent of oxygen $= 8$.

0·446 gm. of the oxide contain 0·374 gm. of the metal.

Hence the weight of oxygen it contains is $0·446 - 0·374 = 0·072$ gm.

If 0·072 gm. of oxygen combine with 0·374 gm. of metal, then 8 „ „ „ „ „ $\frac{0·374 \times 8}{0·072}$ „ „

$$= 41·6 \text{ gm.}$$

The equivalent of the metal is therefore <u>41·6.</u>

General Relation of Equivalents.—*Substances react together in the ratio by weight of their respective equiva-*

lents. Hence the equivalent of any substance, in grams, is the number of grams of it required to react with the equivalent, in grams, of any other substance.

Thus 35·5 gm. of chlorine combine with 1 gm. of hydrogen, so that the equivalent of chlorine is 35·5. But 39 gm. of potassium react with 35·5 gm. of chlorine; hence the equivalent of potassium is 39.

Similarly 32·5 gm. of zinc will precipitate 108 gm. of silver from a solution of silver nitrate. But 32·5 is the equivalent of zinc; hence 108 is the equivalent of silver.

(xii) 1 gm. of silver when heated in chlorine yields 1·329 gm. of silver chloride. What is the equivalent of silver?

1·329 − 1 = 0·329 gm. = weight of chlorine.

Now the equivalent of chlorine is 35·5.

If 0·329 gm. chlorine combine with 1 gm. silver,

then 35·5 gm. " " " $\frac{1 \times 35{\cdot}5}{0{\cdot}329}$

= 108 gm. silver.

∴ equivalent of silver = 108.

(xiii) 2 gm. of gold chloride, on heating, yielded 1·3 gm. of gold. Find the equivalent of gold.

2 − 1·3 = 0·7 gm. = weight of chlorine.

If 0·7 gm. chlorine combine with 1·3 gm. of gold,

then 35·5 " " " " $\frac{1{\cdot}3 \times 35{\cdot}5}{0{\cdot}7}$

= 66 gm. gold.

∴ equivalent of gold = 66.

(xiv) The equivalent of aluminium is 9·0. What

weight of aluminium chloride could be obtained from 12 oz. of aluminium?

9 oz. aluminium combine with 35·5 oz. chlorine,

$\therefore$ 12 oz. ,, ,, ,, $\dfrac{35{\cdot}5 \times 12}{9}$

$= 47{\cdot}3$ oz. chlorine.

$\therefore$ weight of aluminium chloride obtainable $= 12 + 47{\cdot}3$

$= \underline{59{\cdot}3 \text{ oz.}}$

(xv) If the equivalents of iron and copper are 28 and 31·8 respectively, how much copper could be displaced from a solution of copper sulphate by 10 gm. of iron?

28 gm. of iron would displace 31·8 gm. of copper,

$\therefore$ 10 gm. ,, ,, ,, $\dfrac{31{\cdot}8 \times 10}{28}$

$= \underline{11{\cdot}4 \text{ gm. of copper.}}$

PROBLEMS.

1. 16 gm. of oxygen combine with 24·32 gm. of magnesium. What is the equivalent of magnesium?

2. In 162 gm. of zinc oxide there are 130 gm. of zinc. What is the equivalent of zinc?

3. When 5·6 gm. of calcium oxide were analysed they were found to contain 4·0 gm. of calcium. Find the equivalent of calcium.

4. 10 gm. of lead oxide were heated in a current of hydrogen until the action was complete. If the equivalent of lead is 103·5, what weight of lead was left?

5. In 3·5 gm. of carbon monoxide, there are 1·5 gm. of carbon. Find the equivalent of carbon.

6. 1 gm. of a metal, on oxidation, yielded 1·25 gm. of the metallic oxide. What is the equivalent of the metal?

7. 10 gm. of a metal, on oxidation, yielded 18·9 gm. of the metallic oxide. Calculate the equivalent of the metal.

8. 2·479 gm. of a metallic oxide yielded, on reduction, 1·950 gm. of metal. Find the equivalent of the metal.

9. On heating the oxide of a metal, oxygen was evolved. The loss in weight on 4·32 gm. of the oxide was 0·32 gm. Calculate the equivalent of the metal.

10. To oxidize completely 2·00 gm. of lead, 224·6 c.c. of oxygen (measured dry at N.T.P.) are required. Calculate the equivalent of lead.

11. A compound consisting of sodium and hydrogen was analysed. It was found that the percentage by weight of sodium in the compound was 95·8. What is the equivalent of sodium?

12. On heating calcium in hydrogen, a compound of the two elements is formed. The weight of the compound is found to be 5 per cent greater than the weight of the calcium it contains. Find the equivalent of calcium.

13. A specimen of hydrogen sulphide was subjected to the passage of electric sparks, and so decomposed into hydrogen and sulphur. It was found that 50 c.c. of the gas yielded 50 c.c. of hydrogen, both volumes being measured at N.T.P. One litre of hydrogen at

N.T.P. weighs 0·09 gm., and 1 litre of hydrogen sulphide at N.T.P. weighs 1·518 gm. Find the equivalent of sulphur.

14. When palladium hydride is heated, it loses hydrogen, and palladium is left. The hydrogen evolved from 25·60 gm. of palladium hydride measured 133·6 c.c. at N.T.P. What is the equivalent of palladium?

15. The equivalent of zinc is 32·5. Assuming that 2 gm. of hydrogen at N.T.P. occupy 22·4 litres, what volume of hydrogen at this temperature and pressure could be obtained by dissolving 3·25 gm. of zinc in (*a*) dilute hydrochloric acid, and (*b*) dilute sulphuric acid?

16. Zinc will displace copper from copper sulphate solution. 4·000 gm. zinc were found to displace 3·914 gm. copper. If the equivalent of zinc is 32·5, what is the equivalent of copper?

17. Calculate the equivalent of magnesium from the following data: 0·3648 gm. magnesium, on solution in dilute sulphuric acid, gave 364 c.c. hydrogen, measured over water at 15° C. 752·8 mm.

18. To dissolve 0·45 gm. of a metal it was found that exactly 50 c.c. of a solution of an acid were required. The strength of the solution was such that 1000 c.c. of it contained the equivalent in grams of the acid. What is the equivalent of the metal?

19. 0·800 gm. of silver was dissolved in nitric acid, and to the solution an excess of sodium chloride solution was added. All the silver was precipitated as

silver chloride, and the precipitate weighed 1·063 gm. Calculate the equivalent of silver.

20. Red lead is an oxide of lead. On heating, it may be converted into another oxide of lead, viz. litharge, with loss of oxygen. When treated in this way, 5·2500 gm. red lead lost 0·1227 gm. oxygen. The residual litharge was reduced to metallic lead by heating in a current of hydrogen, and the metal so obtained weighed 4·7600 gm. Calculate the equivalents of lead in the two oxides.

21. 15 gm. of carbon were oxidized to a mixture of carbon monoxide and carbon dioxide weighing 45·67 gm. The carbon dioxide was absorbed in weighed bulbs containing caustic soda, and the increase in weight was found to be 29·33 gm. Given that the equivalent of carbon in carbon dioxide is 3, calculate (*a*) the percentage weight of carbon oxidized to carbon dioxide in the above experiment, and (*b*) the equivalent of carbon in carbon monoxide.

22. 1·220 mgm. of radium bromide were converted into radium sulphate by the action of concentrated sulphuric acid. The radium sulphate weighed 1·017 mgm. If the equivalent of bromine is 80, and that of the sulphate (SO_4) group 48, what is the equivalent of radium?

23. 2·67 gm. of an oxide of iron were reduced in a current of hydrogen, and yielded 0·829 gm. water. Calculate the equivalent of iron in this oxide.

24. The equivalent of aluminium is 9. How many grams of aluminium would be required to yield

100 gm. of (*a*) aluminium oxide, and (*b*) aluminium chloride?

25. 12·70 gm. of iodine combine with 10·80 gm. silver. 54·00 gm. silver combine with 17·75 gm. chlorine. How many grams of iodine would combine with 10 gm. of chlorine? [Cf. also p. 23, § 3.]

CHAPTER III

SOME CHEMICAL LAWS

1. **Law of Constant Composition, or Law of Definite Proportions.**—*All samples of any given compound consist of the same elements combined together in a fixed proportion of weight.*

2. **Law of Multiple Proportions.**—*If two elements (or radicals) combine to form more than one compound, then the weights of one of those elements (or radicals) that combine with a fixed weight of the other are in a simple ratio to one another.*

3. **Law of Reciprocal Proportions.**—*Suppose that an element A combines with an element B, and that element B also combines with element C. Then, if A and C combine with one another, the ratio* $\frac{\textit{weight of } A}{\textit{weight of } C}$ *(in the compound of A and C) is in a simple numerical relation to the ratio of the weights of A and C that combine separately with a fixed weight of B.*

[Remember that simple ratios can always be expressed by simple fractions, e.g.:

$1:2 = 0{\cdot}5:1$	$3:5 = 1:1{\cdot}67$
$2:3 = 1:1{\cdot}5$	$5:7 = 1:1{\cdot}4$
$3:4 = 1:1{\cdot}33$	$8:9 = 1:1{\cdot}125$, etc.]

EXAMPLES.

(I) Three specimens of copper, X, Y, and Z, were weighed. The weights were as follows: X = 1·75 gm.; Y = 1·14 gm.; Z = 1·46 gm. X was then converted into copper oxide by dissolving it in nitric acid and igniting the residual copper nitrate. The copper oxide weighed 2·19 gm. Y was converted into copper oxide by dissolving it in nitric acid, precipitating the copper as copper hydroxide by addition of caustic soda, and strongly heating the washed precipitate. The copper oxide weighed 1·43 gm. Z was converted into copper oxide by heating it to constant weight in a current of oxygen. The copper oxide weighed 1·83 gm.

Show that these figures illustrate a law of chemistry, and state the law.

From the fact that 3 samples of the same compound are formed in 3 different ways, it is probable that the law in question is the Law of Constant Composition. This is stated above in § 1.

With the specimen X of copper, 1·75 gm. of copper gave 2·19 gm. of the oxide.

With specimen Y, 1·14 gm. copper gave 1·43 gm. of the oxide,

$$\therefore \text{ 1·75 gm. copper would give } \frac{1·43 \times 1·75}{1·14}$$

$$= 2·19 \text{ gm.}$$

With specimen Z, 1·46 gm. copper gave 1·83 gm. oxide,

$$\therefore \text{ 1·75 gm. copper would give } \frac{1·83 \times 1·75}{1·46}$$

$$= 2·19 \text{ gm.}$$

Therefore a fixed weight (1·75 gm.) of copper in each of the three cases gives the same weight (2·19 gm.)

of copper oxide. Hence all three specimens of copper oxide have the same composition by weight.

(ii) Lead and oxygen combine to form the two different compounds, *litharge* (or lead monoxide) and *lead peroxide*. 2 gm. of litharge contain 1·86 gm. of lead; 2 gm. of lead peroxide contain 1·74 gm. of lead. Are these figures in agreement with the Law of Multiple Proportions?

In *litharge*, 1·86 gm. of lead must have been combined with $2 - 1{\cdot}86 = 0{\cdot}14$ gm. oxygen.

$\therefore$ 1 gm. of lead would have been combined with

$$\frac{0{\cdot}14}{1{\cdot}86} = 0{\cdot}075 \text{ gm. oxygen.}$$

In *lead peroxide*, 1·74 gm. of lead must have been combined with $2 - 1{\cdot}74 = 0{\cdot}26$ gm. oxygen.

$\therefore$ 1 gm. of lead would have been combined with

$$\frac{0{\cdot}26}{1{\cdot}74} = 0{\cdot}15 \text{ gm. oxygen.}$$

Hence the different weights of oxygen that would have combined with 1 gm. of lead in litharge and lead peroxide respectively are in the ratio of 0·075 to 0·15, which is the simple ratio of 1 : 2.

(iii) Two oxides of nitrogen contain respectively A, 63·64 per cent. nitrogen and 36·36 per cent oxygen, and B, 46·67 per cent nitrogen and 53·33 per cent oxygen. Do these figures agree with the Law of Multiple Proportions?

Choose any fixed weight of either element. Suppose we take 63·64 parts by weight of nitrogen as our fixed weight. Then in compound A, we know that the

weight of oxygen combining with this weight of nitrogen is 36·36. In compound B,

46·67 parts by weight of nitrogen combined with 53·33 of oxygen,

∴ 63·64 of nitrogen (the fixed weight) would combine with

$$\frac{53 \cdot 33 \times 63 \cdot 64}{46 \cdot 67} \text{ oxygen} = 72 \cdot 71 \text{ oxygen.}$$

If the law is obeyed, then the two different weights of oxygen, viz. 36·36 and 72·71, that combine with the fixed weight of nitrogen we have chosen (63·64) ought to be in a simple ratio. It is clear that they are, since 72·71 : 36·36 is equal to 2 : 1 within very close limits.

(iv) Ferrous chloride and ferric chloride contain respectively 44·1 per cent and 34·46 per cent of iron. Are these figures in accordance with the Law of Multiple Proportions?

For a change, let us take 100 gm. of iron as our fixed weight of one element.

Then in *ferrous* chloride, the weight of chlorine combining with 100 gm. of iron is

$$\frac{100 \times 55 \cdot 9}{44 \cdot 1} \text{ gm.} = \underline{126 \cdot 8 \text{ gm.}}$$

In *ferric* chloride, the weight of chlorine combining with 100 gm. of iron is

$$\frac{100 \times 65 \cdot 54}{34 \cdot 46} \text{ gm.} = \underline{190 \cdot 2 \text{ gm.}}$$

Are 126·8 and 190·2 in a simple ratio to one another?

ELEMENTARY CHEMICAL CALCULATIONS

BY

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If you cannot tell, divide the smaller into the larger and see what answer you get:

$$\frac{190\cdot2}{126\cdot8} = 1\cdot5.$$

$\therefore$ 126·8 and 190·2 are in the ration of 1 : 1·5, i.e. 2 : 3.

(v) Copper sulphate (anhydrous) and water combine together in two different proportions to form two hydrated salts. The percentage composition of these hydrates is as follows:

	I	II
Copper sulphate, $CuSO_4$	63·96	89·86
Water	36·04	10·14

Are these figures in accordance with the Law of Multiple Proportions?

Suppose we take 63·96 gm. copper sulphate as our fixed weight of one constituent. Then in hydrate I, the weight of water combining with the fixed weight of copper sulphate is 36·04 gm.

In hydrate II,

89·86 gm. copper sulphate = 10·14 gm. water,

$\therefore$ 63·96 gm. „ „ $= \dfrac{10\cdot14 \times 63\cdot96}{89\cdot86}$

$= 7\cdot22$ gm.

But 36·04 : 7·22 approximately as 5 : 1,
and since 5 : 1 is a simple ratio, the Law is obeyed.

(vi) Silver combines with chlorine to form silver chloride, and with oxygen to form silver oxide. The weight of silver chloride obtained from 1·000 gm. silver was found to be 1·329 gm., and the weight of silver oxide given by 1·500 gm. of silver was found to be

1·611 gm. Chlorine and oxygen also combine together, the weight of oxygen combining with 1·000 gm. chlorine being 0·901 gm.

Show that these figures illustrate the Law of Reciprocal Proportions.

The ratio of the weights of oxygen and chlorine that combine with a fixed weight of silver is $\frac{2(1{\cdot}611 - 1{\cdot}500)}{1{\cdot}329 - 1{\cdot}000}$

$$= \frac{0{\cdot}222}{0{\cdot}987} = \frac{0{\cdot}225}{1}.$$

The ratio of the weights of oxygen and chlorine that combine with one another is $\frac{0{\cdot}901}{1}$.

∴ if the Law of Reciprocal Proportions is obeyed in this case, the ratio $\frac{0{\cdot}225}{1} : \frac{0{\cdot}901}{1}$, i.e. 0·225 : 0·901, ought to be a a simple one. But 0·901 = 0·225 × 4 very nearly. Hence the ratio is 1 : 4, which is a simple one; and the law is therefore obeyed.

PROBLEMS.

1. Mercury and iodine form two different compounds, with the following compositions by weight:

	I	II
Mercury	61·2	44
Iodine	38·8	56

Are these figures in agreement with the Law of Multiple Proportions?

2. On analysis, three oxides of manganese were found to contain respectively 63·2, 69·6, and 77·5 per cent of manganese. Show that these figures are in agreement with the Law of Multiple Proportions.

3. Five oxides of nitrogen contain respectively 63·7, 46·7, 36·9, 30·5, and 25·9 per cent by weight of nitrogen. Show that these data illustrate a law in chemistry, and state the law.

4. Phosphorus forms two chlorides. The lower chloride contains 77·45 per cent of chlorine and the higher contains 85·13 per cent of chlorine. Do these figures agree with the Law of Multiple Proportions?

5. Tin forms two sulphides, with the following percentage compositions by weight:

	I	II
Tin	78·8	64·95
Sulphur	21·2	35·05

Illustrate the Law of Multiple Proportions from these figures.

6. Sodium carbonate (anhydrous) will combine with water to form two different hydrates. In the first hydrate, the percentage of water of crystallization is 62·9, while in the second hydrate it is 14·5. Do these hydrates obey the Law of Multiple Proportions?

7. On analysis of two oxides of chlorine, A and B, the following figures were obtained:

2·00 gm. of oxide A contained 1·63 gm. chlorine.
2·35 gm. of oxide B contained 0·91 gm. chlorine.

Are these figures in agreement with the Law of Multiple Proportions?

8. Some lead oxide was prepared in the following ways: (*a*) by heating lead in air; (*b*) by heating lead nitrate; (*c*) by heating lead carbonate. The three

different specimens were then analysed by heating a known weight of each of them in a current of hydrogen and weighing the residual lead. The results obtained are shown below:

Specimen	(a) 1·65 gm.	yielded	1·53 gm. lead.
,,	(b) 2·25 gm.	,,	2·09 gm. lead
,,	(c) 1·16 gm.	,,	1·08 gm. lead.

Show that these figures illustrate a law in chemistry, and state the law.

9. Copper combines with oxygen to form copper oxide and with sulphur to form copper sulphide. Analysis of these compounds give the following results:

Copper oxide contains 79·91 per cent copper.
Copper sulphide ,, 66·53 per cent copper.

Oxygen and sulphur also combine together to form an oxide of sulphur containing 60 per cent by weight of oxygen.

Show that these figures are in agreement with the Law of Reciprocal Proportions.

CHAPTER IV

MOLECULAR AND ATOMIC WEIGHTS

1. *The* **Molecular Weight** *of a substance is the number of times its molecule is as heavy as an atom of hydrogen.*

Thus, the:

M.W. of hydrogen	$= 2$ [H_2]
M.W. of oxygen, O_2	$= 32$ [$O = 16$]
M.W. of ozone, O_3	$= 48$ [$O = 16$]
M.W. of helium, He	$= 4$ [$He = 4$]
M.W. of grape sugar, $C_6H_{12}O_6$	$= 180$ [$H = 1, C = 12; O = 16$]
M.W. of sulphuric acid, H_2SO_4	$= 98$ [$H = 1; S = 32; O = 16$]

2. *The* **Vapour Density** *of a substance is the number of times a certain volume of it in the state of gas is as heavy as the same volume of hydrogen under the same conditions of temperature and pressure.*

3. Numerically, *the vapour density of a substance is half its molecular weight*; for:

$$\text{V.D.} = \frac{\text{Weight of } x \text{ molecules of gas}}{\text{Weight of } x \text{ molecules of hydrogen}}$$

(by Avogadro's Hypothesis).

$$\therefore \text{V.D.} = \frac{\text{Weight of } one \text{ molecule of gas}}{\text{Weight of } one \text{ molecule of hydrogen}}.$$

But the molecule of hydrogen consists of two atoms, and the V.D. is therefore equal to the M.W. divided by 2 [i.e. M.W. $= 2 \times$ V.D.].

4. The *molecular weight of a gas* may be found by

determining its vapour density directly, and multiplying the latter by 2.

(i) A known volume of the gas, at known temperature and pressure, is weighed (say x gm.).

(ii) The volume is corrected to N.T.P. Let the corrected volume be m c.c.

(iii) 1 litre of hydrogen at N.T.P. weighs 0·09 gm.; therefore m c.c. of hydrogen at N.T.P. weigh $\frac{0{\cdot}09 \times m}{1000}$.

(iv) V.D. $= \frac{x \times 1000}{0{\cdot}09 \times m}$, and M.W. $= \frac{x \times 1000 \times 2}{0{\cdot}09 \times m}$.

5. The *molecular weight of a volatile liquid* is usually found by Victor Meyer's method [cf. *Revision Course in Chemistry*, pp. 40, 41]. In this method, a known weight of the liquid is vaporized, and the vapour displaces its own volume of air into a collecting and measuring tube over water. The volume of the air is corrected to N.T.P. (allowing for the pressure of aqueous vapour, p. 10), and the weight of the same volume of hydrogen is calculated, given that 1 litre of hydrogen at N.T.P. weighs 0·09 gm. The weight of liquid taken is then divided by the weight of hydrogen, and the quotient is the vapour density. The latter, multiplied by 2, gives the molecular weight.

6. The *molecular weight of a soluble non-electrolyte* may be determined by the 'depression of the freezing-point' method (otherwise known as the 'cryoscopic' method). [Cf. *Revision Course in Chemistry*, pp. 41–3]. In this method, use is made of the fact that the G.M.W.

(molecular weight in grams) of any non-electrolyte, when dissolved in a fixed weight of a given solvent, will produce a solution freezing at a constant number of degrees below the freezing-point of the pure solvent. Thus the G.M.W. of any non-electrolyte, dissolved in 1000 gm. of water, gives a solution freezing at $-1{\cdot}86°$ C.

To determine the molecular weight of such a substance, therefore, a known weight of it is dissolved in a known weight of pure solvent, the freezing-point of which is known, and the freezing-point of the solution is found experimentally. The difference between the two freezing-points is the 'depression.' Then, by proportion, the number of grams required to produce a certain depression when dissolved in 100 gm. solvent is calculated. The value of this depression is given as K; it varies from solvent to solvent. The solvents most often used for the purpose are water (K, constant depression caused by dissolving G.M.W. of non-electrolyte in 100 gm. water, is here $18{\cdot}6°$) and benzene ($K = 49°$).

The relationship between

w, weight of substance taken,

K, constant depression for G.M.W. of solute in 100 gm. solvent,

t, observed depression in Centigrade degrees,

S, weight of solvent taken, and

M, the molecular weight of solute,

is expressed in the formula:

$$M = \frac{w \times K \times 100}{t \times S}.$$

PREFACE

THIS little book provides in handy form a representative collection of simple numerical problems in chemistry. Every teacher knows the convenience of having a goodly number of such problems to draw upon; and I hope that those here printed will be of especial value, inasmuch as I have given particular attention to two points not always borne in mind. The first point is that, in the chemistry periods, we want to teach chemistry, not mathematics: numerical problems should, therefore, be devised that involve the required chemical knowledge but do not call for lengthy or complex manipulations of figures. To correct for temperature and pressure a volume of 100 c.c. of gas is just as useful, chemically, as to correct a volume of 99·23 c.c.

The second point is that, with young students, more instruction and example in the method of working out and setting down results are necessary than with older students. I have therefore provided a large number of worked examples, and have given hints for the solution of many others. My own teaching experience has proved that such assistance is of very great value, particularly with the weaker members of the set and with those whose time is limited.

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I have also pleasure in thanking two of my pupils, J. M. M. Pinkerton and J. S. Pippard, for checking the answers: an exacting task which they undertook with delightful readiness.

E. J. Holmyard.

Clifton College, Bristol.
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